THE GEOGRAPHY OF THE POLAR REGIONS

OTTO NORDENSKJÖLD
LUDWIG MECKING

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Edited by W. L. G. JOERG

THE GEOGRAPHY OF THE POLAR REGIONS

CONSISTING OF

A GENERAL CHARACTERIZATION OF POLAR NATURE

BY

OTTO NORDENSKJÖLD

AND

A REGIONAL GEOGRAPHY OF THE ARCTIC AND THE ANTARCTIC

BY

LUDWIG MECKING

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A biographical notice of each of the two authors appears on the page facing the beginning of his work.

FOREWORD

The two books by Nordenskjöld and Mecking, here published under a single title, "The Geography of the Polar Regions," form a companion volume to "Problems of Polar Research," published concurrently by the American Geographical Society. The reader will find our knowledge of polar geography set forth in systematic form in the present volume; in the companion volume the emphasis is on problems awaiting solution by future expeditions. The latter is a symposium on Arctic and Antarctic research written by thirty-one authors, most of them experienced in field work in polar and sub-polar regions. Both books aim to give new impetus to the scientific study of the Polar Regions through the free exchange of ideas and plans by leaders of many nationalities.

Dr. Nordenskjöld's book is a general characterization of polar nature. It has hitherto been available only in the author's native language, Swedish. The present translation, like the German and French editions of his earlier book, "The Polar World and Its Borderlands," aims to make accessible to a wider circle of readers the conclusions of this eminent polar student and explorer. Dr. Mecking's work is a description, region by region, of the Arctic and the Antarctic. As commendable as its close organization is the rare judgment which has been exercised in laying the colors on so broad a canvas. Through the portrayal of salient features the individuality of each region is brought out, and the diversity of the polar world—uniform and simple only in the distant view—is made apparent. It is of international value as an instrument of polar research, and the Society welcomes the opportunity to publish it in its present form.

Isaiah Bowman

PART I

GENERAL CHARACTERIZATION

Professor NORDENSKJÖLD occupies the chair of geography in the University of Gothenburg. He has made repeated expeditions to the Polar Regions. As leader of the Swedish expedition of the Magellan region he studied the post-Tertiary deposits in Tierra del Fuego, including the former extension of land ice in South America. The results of this expedition were published under the title "Wissenschaftliche Ergebnisse der Schwedischen Expedition nach den Magelланsländern, 1895–1897" (3 vols., Stockholm, 1905–1907; a general account of this expedition is given in his "La Terre de Feu," Paris, 1902). In 1901–1903 he was leader of the Swedish Antarctic Expedition, of which the scientific results have been published in the "Wissenschaftliche Ergebnisse der Schwedischen Südpolar Expedition, 1901–1903," 7 vols., Stockholm, 1908–1921. Of these he wrote "Die Expedition und ihre geographische Tätigkeit" (Vol. 1, No. 1) and "Die ozeanographischen Ergebnisse" (Vol. 1, No. 2). The general narrative was written jointly with J. G. Andersson ("Antarctica," London, 1905). In 1906 and again in 1909 he went to Greenland for geological and glaciological work ("On the Geology and Physical Geography of East Greenland," *Meddelelser om Grønland*, Vol. 28, No. 2, 1908; "Einige Züge der physischen Geographie und der Entwicklungsgeschichte Süd-Grönlands," *Geogr. Zeitschr.*, Vol. 20, 1914). In 1920–1921 Professor Nordenskjöld's interest in South America led him to visit that continent again ("En resa i Sydamerikas Kordillerastater," *Ymer*, Vol. 41, 1921; "Eine Reise im mittleren Westpatagonien," *Zeitschr. Gesell. für Erdkunde zu Berlin*, 1922; "Südamerika: Ein Zukunftsland der Menschheit," Stuttgart, 1927). On the polar lands he published "Die Polarwelt und ihre Nachbarländer," Leipzig, 1909 (also in French, as "Le monde polaire," Paris, 1913); "Antarktis" and "Die nordatlantischen Polarinseln" (Handbuch der Regionalen Geologie, Nos. 15 and 24, Heidelberg, 1913 and 1921); "Polarnaturen," Stockholm, 1918 (of which the following section of the present work is a translation); "Nord- und Südpolarländer" (in Enzyklopädie der Erdkunde, Leipzig, 1926). The value of Professor Nordenskjöld's work lies not alone in its treatment of specific problems but in its broad synthetic generalization. He is a cousin of Baron Erland Nordenskiöld, the well-known Swedish archeologist and ethnologist, and a nephew of the late Baron Adolf Erik Nordenskiöld, who first accomplished the Northeast Passage in the *Vega*, 1878–1880.

POLAR NATURE: A GENERAL CHARACTERIZATION*

Otto Nordenskjöld

PREFACE

WITH mystic force the Polar Regions, like other distant and little-known parts of the globe, have long appealed to our imagination and interest. To be sure, man in general is primarily interested in studies that deal with man himself, and in this respect the Polar Regions have little to offer, if we disregard the story of man's long struggle to conquer even these, the most inaccessible parts of the globe. But few subjects arouse greater general interest than the description of our natural environment, and this holds especially true of the parts of the globe where the natural forces seem to conspire to prevent and deter human presence and development—regions that man has not yet succeeded wholly in penetrating.

Of the five main types into which nature divides the earth's surface, there are, besides the sea, which alone occupies three-quarters of the globe, and the diversified landscape of the humid temperate zones in which dwell the majority of peoples of Western civilization, three types entirely foreign to us, namely the primeval forests of the tropics, the wide and open spaces of the deserts and steppes, and the Polar Regions.

Whoever is familiar with the Polar Regions knows that precisely the mightiest natural features here have a certain uniformity, and, just as one may speak of a desert nature, one may certainly speak of a polar nature. The present little work, however, does not presume to describe this nature systematically and from all points of view. In the first place, it has been kept somewhat personal and dwells especially on such regions and features of polar nature as I myself have had opportunity to study rather closely. Then, too, my purpose was different. The more closely one gets to know the Polar Regions, the more their uniformity disappears from view and the more the separate individual regions stand out in their characteristics. Not uniform polar nature but the many different types of polar nature it has here been my main task to describe. Perhaps also the time has come to divide the Polar Regions into natural regions according to their most

* Translated for this volume by Dr. Ernst Antevs from the author's "Polarnaturen" (in series: Populärt Vetenskapliga Föreläsningar vid Göteborgs Högskola, N. S., No. 15), Bonnier, Stockholm, 1918.

important natural features, and I here present the preliminary results of such an attempt.

The Swedish edition of the book was printed in 1918. It is an outgrowth of a series of public lectures given in Copenhagen in March, 1916, at the invitation of the Danish section of the Letterstedt Society and the Committee on Coöperation Among Scandinavian Universities and repeated, half a year later, in a somewhat revised and enlarged form, at the University of Gothenburg. It forms a supplement, in a certain sense, to an earlier regional geography of the Arctic and Antarctic that I had published in Swedish in 1907 entitled "The Polar World and Its Border Lands" (German edition, 1909; French edition, 1913). In the present work the lecture form has been retained on the whole, a circumstance which accounts for the fact that it has not always been possible to follow a given problem through or to present a completely rounded discussion of each topic. Nor has it been possible to give complete references to the literature used where the views presented are not based on my own observations. At the end, however, a short list is given of some of the works that contain a general discussion of polar nature or of one of its phases, and to them the reader is referred for bibliographical detail. For the present translation I have unfortunately not been able to undertake a complete revision of the book, but in many cases, nevertheless, it has been possible to include the results of new research down to the end of 1926.

O. N.

Gothenburg, October, 1927.

CHAPTER I

THE CLIMATE OF THE POLAR REGIONS

Importance of Climate As a Geographical Factor

Climate is the natural phenomenon that, more than any other, determines the distribution of the great natural regions of the earth and their limits; every geographic description of the environment must start with climate. And nowhere on earth is nature so completely and directly characterized by the daily regular weather—by what we may call the normal climate—as in the polar lands.

The tropical belt at the equator is characterized by almost unbelievable uniformity of heat and light: the temperature is always evenly warm; day and night follow each other with equal length; and over large areas rain falls regularly at all seasons and in almost the same amount. The farther we proceed from the equator in either direction into the temperate zones, the greater become the contrast and diversity of the different seasons and landscapes: the contrast between the warm, light summer and the long winter with its short days, the irregular alternation between sunshine, rain, and wind, between moist coasts and arid interiors with warm summers and cold winters. But when we approach the Polar Regions this type again changes: the farther we go the colder the summer becomes; so that we here again can speak of a fairly uniform climate—constantly cold, in some parts also with constant snow and wind. Days and nights, too, grow more and more uniform in their alternation, until at the very poles they again become equally long, each now lasting half a year. These peculiar conditions of light, together with the low summer temperature, constitute the first typical characteristic of the Polar Regions.

Temperatures in the Arctic and Antarctic

When we speak of the climate of a place we usually mean first of all its temperature and precipitation. Other factors, such as wind and insolation, usually have only a more local importance, but the rôle of precipitation should never be underestimated. It is difficult to imagine a greater climatic contrast than that existing between a swampy region of the warm, humid belt and a tropical desert, although they may each have about the same mean temperature. But in the Polar Regions differences in precipitation play a relatively subordinate rôle except with regard to the distribution of ice. Temperature is

there the great determining factor, in comparison with which other climatic factors, among which the winds are the most important, characterize local regions, rather. Thus temperature should be discussed first; and in order that an idea of the polar climate and its diversity may be had at the very beginning a table has been compiled of monthly temperatures from a number of polar stations in the better-known portions of the Arctic.[1]

TABLE I—MEAN MONTHLY TEMPERATURES (IN DEGREES C.) AT A NUMBER OF PLACES IN THE ARCTIC

	Arctic Sea, about 83° N 90° E	North Greenland, about 82° N 64° W	Ivigtut, 61° 12′ N 48° 11′ W	Hammerfest, 70° 40′ N 23° 46′ W	Jan Mayen, 71° N 8½° W	W. Spitsbergen, about 78° N 16° E	Franz Josef Land, about 80° N 56° E	Ustyansk, 71° N 136½° E	Point Barrow, 71° 20′ N 156° 20′ E	Gulf of Boothia, about 69° N 89° W
Jan. . .	−35.6	−36.2	− 7.6	− 5.2	− 7.3	−14.1	−26.2	−41.3	−28.3	−32.3
Feb. . .	−35.8	−37.5	− 7.5	− 4.7	− 4.4	−20.7	−26.8	−37.1	−28.9	−33.6
March .	−30.3	−34.5	− 4.8	− 3.6	−10.3	−19.0	−23.9	−29.2	−26.8	−29.4
April . .	−22.8	−23.9	− 0.9	0.0	− 2.7	−13.1	−17.5	−19.6	−17.0	−18.6
May . .	−11.0	− 9.5	+ 4.4	+ 3.4	− 4.0	− 5.6	− 8.5	− 5.0	− 6.1	− 6.1
June . .	− 1.8	+ 0.7	+ 7.9	+ 7.9	+ 1.8	+ 1.4	− 0.8	+ 5.6	+ 0.4	+ 1.0
July . .	+ 0.1	+ 3.2	+ 9.7	+11.8	+ 3.5	+ 4.3	+ 1.4	+10.4	+ 3.6	+ 4.6
Aug. . .	− 1.8	+ 1.4	+ 8.3	+10.8	+ 3.1	+ 2.8	+ 0.4	+ 6.1	+ 3.3	+ 2.9
Sept. . .	− 9.0	− 8.6	+ 4.8	+ 6.9	+ 1.9	− 0.5	− 5.7	+ 0.9	− 2.5	− 2.5
Oct. . .	−21.8	−21.8	+ 1.0	+ 1.6	+ 2.1	− 6.9	−15.7	−11.2	−16.0	−11.6
Nov. . .	−28.7	−28.3	− 3.3	− 2.0	− 1.9	−10.8	−22.7	−28.2	−21.8	−21.2
Dec. . .	−32.2	−31.2	− 6.5	− 3.8	− 9.6	−16.3	−25.4	−36.9	−27.4	−36.0
Year	−19.2	−19.3	+ 0.5	+ 1.9	− 2.3	− 8.2	−14.3	−15.5	−14.0	−14.8

This table, which we may further compare with the temperature diagram, Figure 1, shows (as will be still more apparent from figures to be given later) that the popular and widespread idea that the polar climate is uniform, or that all polar regions have about the same temperature, is entirely wrong. The contrasts between summer and winter temperatures or between the different regions at the same seasons are perhaps not quite so great as they are in the northern belt of the temperate zone, but they are seldom surpassed elsewhere on earth.

To make clear these climatic contrasts between different polar regions and get a clearer conception of the types we have to deal with, we will first consider three particularly characteristic regions. For easier comparison places situated fairly far from the poles and the

[1] Partly with the help of the compilation in Julius Hann's Handbuch der Klimatologie, 3 vols., 3rd edit., Stuttgart, 1908–11, specifically Vol. 3.

innermost polar regions are chosen: namely Upernivik in western Greenland, Verkhoyansk in eastern Siberia, and Cape Adare at the northern rim of the Antarctic Continent.

The mean temperature in these places has been compiled in Table II, below. For Cape Adare the months are indicated which in the southern hemisphere correspond to those given in the northern.

The North Greenland settlement Upernivik may be regarded as a typical place so far as Arctic climate in the more accessible regions is concerned. During the three coldest winter months, January to March, the temperature here is almost uniformly –22° C. That is, the temperature that during cold winters may prevail for a week or so in the interior of central Sweden exists here during the whole winter, but it is nevertheless not an entirely new type of winter climate. Towards the end of April spring begins and before long makes itself clearly felt; in June the temperature has risen above the freezing point, and in July and August the average temperature is +5°, somewhat over 10° colder than in Sweden. In spite of this relatively low temperature, however, there is a real summer, temperature being measured in the shade. In the sunshine the heat is substantially greater, and in these northern regions the sun stands day and night for months at almost the same height above the horizon. September is still relatively mild; but in October the temperature has fallen far below freezing, and winter begins. The average temperature of the year is –8.7°, farther below freezing than southern Sweden is above.

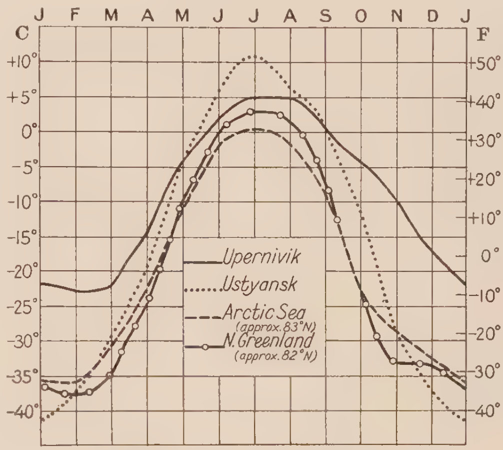

FIG. 1—Diagram of mean monthly temperatures at a number of Arctic localities. Upernivik (Greenland), half-maritime type of climate in the outer polar belt; Ustyansk (Siberia), continental transition climate; North Greenland, high-Arctic land climate; Arctic Sea (after Nansen), ice-covered-sea climate.

In spite of these great differences from Swedish temperatures, we have this type of climate in Sweden at least under extreme conditions. Upernivik lies, however, only halfway between the north pole and the latitude of Stockholm; and nearer the pole the temperature of course decreases. However, the coldest winter on the earth[2] is to be found in the interior of eastern Siberia, so far as we know in the vicinity of

[2] At least at or near the level of the sea; at the south pole, 3000 meters above the sea, it may be colder.

Verkhoyansk, which is situated a little north of the Arctic Circle in the valley of the Yana. Here, protected from the wind, the mean temperature during the whole of January often sinks below −50° C. and occasionally even to −70°. For comparison it may be stated that the former temperature is only exceptionally observed on minimum thermometers in the coldest regions of Scandinavia.

TABLE II—MEAN MONTHLY TEMPERATURES (IN DEGREES C.) AT THREE CHARACTERISTIC PLACES IN THE ARCTIC AND ANTARCTIC

	UPERNIVIK 72° 47′ N 55° 53′ W	VERKHOYANSK 67° 33′ N 133° 24′ E	CAPE ADARE 71° 18′ S 170° E
Jan.	−22.0	−50.5	−22.9 (July)
Feb.	−22.8	−44.1	−25.3 (Aug.)
March	−22.0	−31.1	−24.4 (Sept.)
April	−14.6	−13.7	−19.1 (Oct.)
May	− 4.2	+ 1.9	− 8.2 (Nov.)
June	+ 1.7	+12.5	− 0.2 (Dec.)
July	+ 5.0	+15.4	+ 0.7 (Jan.)
Aug.	+ 4.9	+ 9.9	0.0 (Feb.)
Sept.	+ 0.5	+ 2.4	− 7.9 (March)
Oct.	− 4.1	−14.9	−12.1 (April)
Nov.	− 9.9	−36.9	−19.5 (May)
Dec.	−17.0	−47.0	−24.6 (June)
Year	− 8.7	−16.3	−13.6
Winter (6 months)	−16.3	−37.4	−21.5
Summer (6 months)	− 1.1	+ 4.7	− 5.8

Nevertheless this region should not be thought to represent the typical polar climate; only in a restricted sense, i.e. only during winter, can the climate be called polar at all. Summer, on the other hand, with a temperature of 30° in the shade, is warm even according to our conditions; and since the summer temperature is far more important in determining the character of a region than is the winter's cold, and especially because the vegetation under these conditions is rather luxuriant, we rightly place Verkhoyansk in the temperate zone in spite of the fact that the mean temperature of the year (−16.3° C.) is substantially lower than in Upernivik.[3]

The cause of these seemingly remarkable contrasts—on the one hand a cold polar climate, on the other hand a much colder but, on account of the summer heat, temperate climate—is easily explained and fairly well known. A large mass of land accentuates all temper-

[3] On the diagram, Fig. 1, I have chosen for comparison Ustyansk just south of the mouth of the Yana. Its climate belongs to the same type as that of Verkhoyansk, but, in spite of less severe winters, it is transitional to a real polar climate because of its lower summer temperature.

ature extremes, especially in temperate and cold regions: the summer is warmer and the winter colder than in the vicinity of the ocean. Few regions on the globe, however, are so little influenced by the sea as is eastern Siberia; and here therefore is to be found the most extreme continental climate on the globe. Upernivik, on the contrary, lies on the coast, even though on a partly closed sea; and it can be assumed that the climate there is fairly maritime.

Still more maritime types of climate than at Upernivik are fairly well known in the Polar Regions. Nansen's expedition spent three years on the *Fram* in the Arctic Sea within four to ten degrees of the north pole. The results of its observations are given in Table I (column 1), and we shall return to this subject later. It is more difficult to find a real continental climate in the Arctic. A long series of observations from the interior regions of real polar countries is still completely lacking, and north of latitude 70° N. there are few such countries. As a consequence of the investigations of recent years, it is, therefore, natural to seek comparisons in the Antarctic Regions and ask what these have to give. First, by a comparison between these two cold regions, north and south, separated by the rest of the earth, we gain some idea of polar nature. In such a comparison lies the great importance to modern science of exploration in the Antarctic Regions as well as for the prospects it affords of the interpretation of a whole series of climatic and geophysical problems of importance in the study of the earth. Very much still remains to be done; but the expeditions of the last decades have solved the broad general problem regarding the distribution of land and sea in these regions. Around the south pole the seventh continent of the earth is to be found; around the north pole is found the ocean whose actual discovery was the chief result of Nansen's famous voyage.

From these facts we should be inclined to believe that the summers in the Antarctic Continent are warmer and the winters colder than in the north. Such, however, is absolutely not the case. Although the climate at Cape Adare (see Tables II and IV) is not especially typical, it can be fairly well compared with that at Upernivik. The summer is very much colder, and the winter even is distinctly colder than at Upernivik. While the temperature at Upernivik, low as it is, is sufficient to give rise to a rather luxuriant flora and fauna, land organisms are very scarce at Cape Adare. It might perhaps be supposed that the temperature at Cape Adare station, situated on the coast, is determined in winter time by the continent, in summer by the sea; such a view was held by many not long ago. But this supposition cannot be right for the reason among others that such a cold summer can hardly be found even at the north pole in the heart of the Arctic Sea.

The truth is—as became evident perhaps for the first time from

the observations during our Swedish expedition in 1901–1904—that the climate on the Antarctic coast is of an entirely new type. Winter, to be sure, is not so cold as in the interior of the extensive northern land masses or even in the coastal regions completely under their influence, but it is, as a rule, colder than at the Arctic coast stations in the same latitude, and the summer is the coldest known on the earth. The climate consequently is, so to say, more polar than that in the Arctic Regions. Both summer and winter are colder, so that the climate is neither continental nor maritime. It should be recalled, also, that the climate of the sea round the north pole in winter is entirely too cold to be classified as maritime.

As a matter of fact within the actual Polar Regions one can only seldom speak of a distinctly maritime or continental climate in the usual sense. The explanation of this deviation from the two main accepted categories is in my opinion to be found in the fact that in the Polar Regions neither sea nor land occurs in vast extent with their normal characteristics; but both, the Arctic Sea and the Antarctic Continent, are covered by perpetual ice. The ice itself is caused, to be sure, by the low polar temperature, especially the cold summer, but at the same time it greatly influences the polar climate. The climatic type is neither continental nor maritime: it is *glacial*. A land-ice and a sea-ice climate have to be distinguished. Their characteristics will be explained presently. This much is evident that, while elsewhere on the earth the solar climate is influenced chiefly by land and sea, at times more by the one, at times more by the other, in the Polar Regions there are three important factors, land, sea, and ice. It is obvious that on account of this the whole problem is highly complicated; this may be one of the reasons why thus far it has been given so little attention.

The Three Types of Polar Climate (Land, Sea, and Ice Climates) and Their Regional Distribution

In order to obtain a better idea of the temperature conditions in the Arctic, we will first study the isotherms on the maps of the natural regions in Chapter VI (Figs. 23 and 24), on which, however, only summer temperatures have been indicated, and also return to Tables I and II.[4]

To begin with, then, we find, as already stated, that the climate of the Polar Regions at the same distance from the pole often presents

[4] The maps show the approximate course of the isotherms in the Arctic and Antarctic Regions during the warmest summer month. I, Outer Polar Belt; II, High-Polar Belt, with the four subdivisions A-D of its Arctic representative; III, Antarctic Province. II and III together constitute the inner Polar Regions, i. e. the area within the 5° C. mean isotherm of the warmest month. The much colder summer in the south is evident. In both maps the actual limits of the polar climate have tentatively been indicated, calculated according to Vahl's principle and after the formula given on p. 73.

great contrasts. At or close to the Arctic Circle the climate on the eastern side of the Atlantic is distinctly maritime (the northwestern coast of Norway); in other regions even relatively near the coast it is, as a rule, more or less typically continental, occasionally exhibiting great changes in temperature (Verkhoyansk). Only exceptionally is it distinctly polar in the ordinary sense or according to the view that it should be influenced by perpetual ice. Only at the southern end of Baffin Island is there in that latitude a real high-Arctic climate, which in summer and winter is incomparably colder than in the same latitude on the relatively near-by coast of western Greenland. The contrasts within the inner Polar Regions are, however, not so great; and the observations at hand in this area from various polar expeditions seldom differ greatly from the temperature conditions at Upernivik. The observations of these expeditions, however, easily give the impression that the climate here is more uniform than it actually is. Naturally most of the winter stations are situated on the coast, and the climate consequently is influenced both by the sea and by a land more or less ice-covered. The relatively mild winter at Upernivik is evidently influenced by the sea. At the enclosed sounds (Smith Sound, etc.) in the north-northwestern corner of Greenland, 10° farther north, a distinctly colder climate prevails. The average temperature of the air is between –15° and –20°; and instead of a winter temperature of –22° the extreme low temperature of about –36° exists for three to four months (Fig. 1). May and September have about –10°, but the summer itself does not lack warmth, the mean temperature for July being +3° to +4°, hardly 2° lower than at Upernivik. Disregarding the influence of the ice this climate should, I think, be classified as distinctly continental; this becomes still more evident if we compare it with the temperature in Franz Josef Land, situated in about the same latitude. Or, still better, it can be compared with Spitsbergen, where the mean temperature of the three winter months is only –18°. The summer in Franz Josef Land is some 2° lower than in North Greenland, while the winter is more than 10° warmer. The summer, however, in the interior of the fiords of Spitsbergen is rather warm, which makes a study of the polar climate very complicated.

In order to get an exact idea of the conditions it is evidently necessary to start from stations where only one of the three main factors—sea, land ice, and land—is chiefly effective. The difficulty is to find such places. It is easiest to study the temperature on the open sea. Far out in the North Atlantic is to be found the small rocky island Jan Mayen, whose temperatures are given in Table I (col. 5). The average for the four coldest months is –8°, for the two warmest about +3°—in relation to its situation an extremely cool summer, but a winter so mild that it can hardly be called polar. We have here the direct

influence of a subpolar sea covered by drifting ice—a sea, however, whose own warmth also plays a rôle in winter.

That conditions, especially in winter, become quite different even in smaller archipelagoes around which the ice cover remains unbroken is evident from what has been said regarding Franz Josef Land and its mean winter temperature of about −30°. However, we have still better material for the study of this question in the important observations made during Nansen's famous drift across the Arctic Sea. In Table I (col. 1) and in the diagram (Fig. 1) the figures for three years are shown as a unit. In itself it is of course not strange to find on the sea in the vicinity of the pole a temperature during the warmest month of the year of about 0° C., the coldest known on the northern hemisphere at sea level. But it is much stranger to find that the other seasons, except winter, almost exactly agree with those prevailing in northern Greenland at Smith Sound, just characterized as continental. A sea covered by thick welded masses of ice evidently has only a small influence on the winter temperature.[5]

About the temperature in the interior of the Arctic ice sheets extremely little is known. The only one among them of really continental extent is the Greenland ice cap; but of its interior we have only a few short series of summer observations, and from them it is impossible to form a picture of the climate as a whole. Among them, however, are J. P. Koch and Wegener's important but unfortunately not yet published observations made at their ice station Borg situated on the eastern side of Greenland on a glacier near the sea and only 63 meters above sea level. The temperature there during the period of observation was about 5° lower than at Danmarks Havn, situated on the outer coastal belt. From what we know it becomes highly evident that the mean annual temperature and especially the summer temperature is essentially lower in the interior of the inland ice than in other polar areas. It is on this subject, however, that Antarctic exploration has produced one of its most important results, and we shall find later that this corroborates the view which has just been put forth.

The observations at hand from the interior of those portions of the Arctic Regions that are free from snow and ice in summer, except the northernmost parts of the continents, are if possible still less complete. The contrasts between coastal and continental climates can in the meantime be studied indirectly by comparison of observations made along the outer coastal belt with those made nearer the

[5] Quite recently Finn Malmgren, in discussing the results of the Norwegian *Maud* expedition (Sci. Results Norwegian North Polar Exped. on the Maud, 1918–25), has tried to determine the heat transport to the air from the sea through the ice of the frozen Siberian Sea. He calculates the quantity of heat conveyed during eight winter months to be 7670 gr.-cal./cm.², a quantity that would on an average be sufficient to raise the temperature of the atmosphere in the lowest 150 meters by 6.9°. This, it will be noted, is a rather considerable amount.

heads of the fiords which at many places deeply penetrate polar regions that are heavily ice covered. There are a few observations of this kind from West Spitsbergen; but, mainly, much valuable material has been gathered by the Danes on the west coast of Greenland. In the table below, Nanortalik and still more so Sagdlit represent the cool and typical coastal climate influenced in summer and winter by the sea covered with drifting ice, while Ivigtut is situated somewhat farther north, deep in a fiord. The same is the case with Kornok and Godthaab, the latter of which, however, is situated a little away from the mouth of the fiord about 15 kilometers from the open sea.

TABLE III—MEAN MONTHLY TEMPERATURES (IN DEGREES C.) AT PLACES ON THE WEST COAST OF GREENLAND

	NANORTALIK* 60° 8′ N	SAGDLIT* 60° 16′ N	IVIGTUT* 61° 12′ N	GODTHAAB* 64° 10′ N	KORNOK* 64° 32′ N
Jan. . . .	−5.7	−5.3	−7.6	−10.2	−11.3
Feb. . . .	−5.7	−5.4	−7.5	−10.3	−11.1
March . .	−3.4	−3.5	−4.8	− 8.0	− 8.6
April . .	−0.2	−0.4	−0.9	− 4.0	− 3.8
May . .	+ 2.9	+ 2.1	+ 4.4	+ 0.8	+ 2.0
June . . .	+ 5.1	+ 3.9	+ 7.9	+ 4.5	+ 6.3
July . . .	+ 6.2	+ 4.4	+ 9.7	+ 6.6	+ 8.2
Aug. . . .	+ 6.2	+ 4.5	+ 8.3	+ 6.2	+ 7.5
Sept. . .	+ 4.4	+ 3.8	+ 4.8	+ 3.0	+ 3.0
Oct. . . .	+ 1.5	+ 1.3	+ 1.0	− 1.0	− 1.5
Nov. . .	−0.6	−0.6	−3.3	− 4.7	− 5.4
Dec. . . .	−3.4	−3.2	−6.5	− 8.1	− 8.9
Year . .	+ 0.6	+ 0.1	+ 0.5	− 2.1	− 2.0

* Length of record at Ivigtut, Godthaab, and Kornok, 27 years; at Sagdlit and Nanortalik, 7 years (1907–1912 and 1915).

From these observations it is evident how much the climate of the Greenland coast is influenced by the sea: while the winter at Sagdlit is about 3° milder than at Ivigtut, the summer is 5½° colder. And yet both are coastal stations, although the one situated far up in a fiord is much less influenced by the sea. Much greater contrasts with the actual interior are to be expected at places where the coastal belt is wide; but unfortunately there are as yet no long series of observations to show this.

However, this climate is not entirely unknown. The ice-free belt of land reaches its greatest width in the Holsteinsborg district just north of the Arctic Circle in western Greenland. The whole belt is here about 190 kilometers wide, and the strip between the heads

of the fiords and the inland ice is nearly 100 kilometers wide. In the latter part of June, 1909, I made a journey here to the inland ice and found natural conditions and a climate which, if not entirely unknown—the region had been visited by Danish scientists—were nevertheless highly unexpected and remarkable. The whole area has the aspect of a dry steppe region of a peculiar type: there are salt lakes and saline efflorescences, lakes with no outlets, peculiar phenomena of weathering, loess, and wind-blown sand. The snowfall in winter must be exceedingly small. While the temperature in Holsteinsborg during that week was fairly normal, about $+9°$, near the inland ice it was above $+15°$ C. This is a summer figure unknown elsewhere in the Polar Regions and comparable to the summer temperature in southern and central Sweden. Of course, many objections can be made to these temperature records because of their short period, but they give us a first possibility of reconstructing in figures what perhaps can be called a polar continental climate without ice. Thus in all probability the low summer temperature of the polar climate, which is its best known and most conspicuous feature, is mainly due to the cooling effect of the ice and the sea.[6]

It is important to notice that the region under discussion lies rather far from the pole; a series of observations from the ice-free area at the northern end of Greenland or from the interior of some of the islands of the American Arctic Archipelago would of course be still more valuable. It is another problem to try to determine why such a region, which in summer, at least sometimes, is distinctly "temperate," can exist as an enclave in the interior of the Polar Regions at the edge of the perpetual ice. The warmth does not seem to be directly due to warm föhn winds sweeping down from the ice; but it probably is connected with the high-pressure area over the inland ice and the air masses descending on it, partly directly and partly indirectly because of the strong insolation in the dry, clear, and relatively quiet air. It is consequently not certain that this is really a case of a polar continental climate. For a closer understanding a longer series of observations and a more thorough knowledge of the upper strata of the air are needed. To obtain such knowledge is one of the leading objects of the investigation inaugurated by W. H. Hobbs on his two expeditions to the western margin of the Greenland inland ice in the summers of 1926 and 1927.

Before summarizing what has been said about the polar climate we will consider the climate of the Antarctic Regions. Contrary to

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[6] During W. H. Hobbs's expedition to the same region in July and August, 1926 (W. H. Hobbs: The First Greenland Expedition of the University of Michigan, *Geogr. Rev.*, Vol. 17, 1927, pp. 1–35; reference on pp. 20–24), a difference in temperature between Holsteinsborg and the edge of the inland ice was observed, but it was much smaller in amount (about 1° C.). It is difficult to explain why the weather was so warm during my visit in 1909. Just how much the temperature increases toward the inland ice can obviously be determined only when much longer series of observations are available.

expectations, it differs in several respects from that of the Arctic; and even after the important discoveries made by the latest expeditions evidently much remains to be learned about these regions. It becomes more and more evident that the Antarctic climate is almost as diversified as that of the Arctic.

For a long time it had been held that the summer climate of the coast of the Antarctic Continent is the coldest on earth. This has been attributed to the influence of the sea; but we have seen that this explanation is unsatisfactory, for in that case the islands in the Arctic Sea, for example, ought to have equally low temperatures. On the other hand, it was long thought that the Antarctic enjoyed a relatively mild winter. The later discovery that this was not the case should, after Nansen's experiences in the interior of the Arctic Sea, not have been a surprise even for those who regarded the Antarctic climate as "maritime."

A table is given on the next page showing the temperature in a number of the most important places in the Antarctic Regions.

The first knowledge of the Antarctic winter we owe to Borchgrevink's wintering at Cape Adare. The climate he found there cannot really be called unexpected: during the three coldest months the temperature was about 2° lower than at the not very cold Upernivik (see Table II, p. 8) situated at about the same distance from the equator; during the spring and summer it was about 4° lower. The fact that the autumn, March to June, in comparison with the corresponding months in the north, was 8½° colder might have been due to chance. It was known before that the summer was extremely cold; during the warmest month that year the temperature, however, reached about freezing. Scott's and Shackleton's several winterings in the same region on the east coast of South Victoria Land, but about 700 kilometers nearer the pole (column 2 in Table IV), recorded essentially lower temperatures, not so much during the winters as during the other seasons. A mean temperature for the three warmest months of less than −5°, lower consequently than a cold January at Stockholm, was something undreamed of before the modern South Polar expeditions, at any rate in this latitude. The autumn also is exceedingly cold—a feature almost as characteristic for the Antarctic Regions as the low temperature in summer. But the temperatures in winter are not especially low, and thus perhaps the peculiar condition arises that the mean temperature during all the six months of the winter half-year here remains almost unchanged at nearly −25°. On the whole the climate is rather colder than at the same latitude in the north, but the contrasts between the seasons are much less. The type could be regarded as polar maritime were it not for the fact that even a superficial comparison with areas in the north belonging to this type shows that it is not.

All this indicates that we have before us a new type of climate, which is not maritime and still less continental; and the question arises whether it can serve as the normal Antarctic type. So it was once thought, and therefore it was a surprise when Amundsen at his winter station Framheim, a little farther south and about 600

TABLE IV—MEAN MONTHLY TEMPERATURES (IN DEGREES C.) AT A NUMBER OF PLACES IN THE ANTARCTIC

	Cape Adare (S. Victoria Land) 71° 18′ S 170° E	South Victoria Land about 77° 45′ S 166° E	Framheim* (Amundsen) 78° 38′ S 163° 37′ W	South Pacific Ocean (Belgica Exped.) about 70° S 86° W	Snow Hill 64° 22′ S 57° 0′ W	South Orkneys 60° 44′ S 44° 39′ W	South Atlantic Ocean (Filchner) 65°–73° S	South Indian Ocean (Gauss Exped.) 65° S 90° E
Jan.	+ 0.7	− 4.5	− 5.7	− 1.2	− 0.9	+ 0.3	(−2.0)	− 0.9
Feb.	0.0	− 8.9	−12.6	− 1.1	− 3.5	+ 0.6	− 6.2†	− 3.1
March	− 7.9	−15.3	−21.9	− 8.9	−10.3	− 0.2	−10.4	− 8.3
April	−12.1	−22.7	−31.1	−11.8	−13.8	− 2.3	−16.0	−15.6
May	−19.5	−23.6	−32.8	− 6.5	−18.2	− 6.0	−22.3	−14.1
June	−24.6	−24.4	−34.1	−15.5	−19.7	− 8.9	−26.0	−17.5
July	−22.9	−25.9	−36.5	−23.7	−20.8	−11.7	−26.0	−18.1
Aug.	−25.3	−25.9	−36.8	−11.3	−19.2	− 8.6	−23.0	−21.9
Sept.	−24.4	−24.3	−34.1	−18.6	−15.6	− 5.7	−12.9	−17.7
Oct.	−19.1	−19.0	−25.6	− 7.8	− 9.6	− 3.3	−10.2	−12.9
Nov.	− 8.2	−10.0	−13.0	− 6.9	− 8.1	− 2.0	− 6.8	− 6.9
Dec.	− 0.2	− 3.9	− 4.6	− 2.3	− 2.0	− 0.8	.....	− 1.3
Year	−13.6	−17.4	−24.1	− 9.6	−11.8	− 4.1	.....	−11.5

* The figures for Framheim do not give the directly observed temperatures but are reduced according to Hann's suggestion (*Meteorol. Zeitschr.*, Vol. 31, 1914, p. 553; see also p. 65).

† In February the average latitude of the expedition was 77° 45′ S.

kilometers to the east of Cape Adare, found a climate essentially different and, above all, colder. As Table IV shows, this is evident especially in the winter temperature, which is about 10° lower than in McMurdo Sound (column 2); but the whole summer is exceedingly cold, although only a degree or two colder than there. The *observed* average for January was −9.7°; and, reduced as above, the temperature for the two warmest months is still below −5°. The observed minimum temperature of the air, −59°, as well as the average winter cold, is fully comparable with the lowest known in the Arctic Regions. The mean annual temperature of almost −25° (observed temperature) is the lowest existing measured mean, and still more remarkable, almost beyond conception, is the fact that during the whole year the temperature never once rose to freezing point. The climate at Framheim, however, differs also in another and more favorable respect from that

at Scott's and Shackleton's station on the east coast of South Victoria Land: it was incomparably more quiet, in that the cold-bringing hurricanes characteristic of the Antarctic were practically non-existent. In this circumstance is evidently to be found one of the explanations of the low temperature, which here, as well as in the Arctic, is frequently, though not always, connected with calm weather and intensive radiation. On such occasions the temperature in the upper strata of the air is partly higher than that at the earth's surface; and stronger wind causes mixing of the air, which raises the temperature.

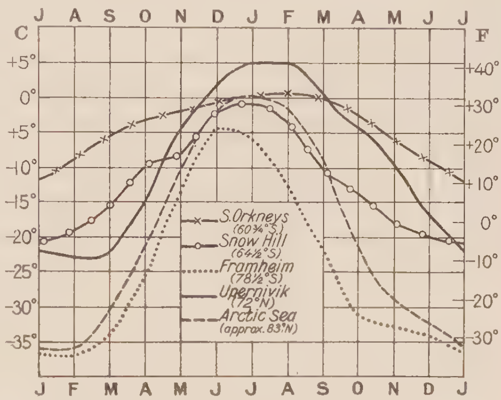

FIG. 2—Diagram of mean monthly temperatures at three Antarctic localities: the South Orkneys with a maritime marginal climate; Snow Hill and Framheim, with a land-ice climate, the latter station with the lowest annual mean temperature hitherto known. For comparison the temperature curves are given of Upernivik and of Nansen's observations in the Arctic Sea.—The months at the lower edge refer to the northern stations.

The maritime type of Antarctic climate is fairly well known from the long ice drifts of the *Belgica* (de Gerlache) and the *Deutschland* (Filchner)—the first-mentioned in the extreme south of the Pacific, the latter in the extreme south of the Atlantic. In the former area the winter is distinctly mild, much like that off West Spitsbergen. While the summer usually is cold, though not so cold as at the border of the inland ice, here as well as in the North Atlantic the sea apparently tempers the winter's cold. In Weddell Sea, the southernmost part of the Atlantic, the contrary is the case.[7] Here the winter temperature is of the same type as in the interior of the pack ice in the Arctic, about as low as at Franz Josef Land (which is nearer the pole than Weddell Sea); but the summer is much colder, the temperature of the warmest month being –2°. The prevalence of low summer temperatures even in the islands situated farthest from the pole is shown by the series given in column 6 of Table IV from the long Scottish and Argentine observations in the South Orkneys. The winter here, however, is mild.

None of these series of observations suggests the *cause* of the peculiar differences from the Arctic climate that evidently exist. The first Antarctic material that pointed directly to or hinted at the cause may have been what was brought home from the Swedish winter

[7] The Atlantic region is on the whole much colder than the Pacific, both as regards temperature of the water and as regards temperature of the air along the coasts and over the sea.

station where I spent the years 1902–1903 and where the meteorological observations were directed by Gösta Bodman. The temperature diagram itself (Fig. 2) does not appear very remarkable, the winter temperature being –20° and the temperature of the two warmest months –1.5°; but even this is exceptionally low for a station situated in the latitude of Trondhjem and at sea level. Of the greatest interest here is the connection between wind and temperature. As a rule temperatures in the Polar Regions are lowest during calm, clear weather; and generally the stronger the winds the warmer it is, even though storm winds from the polar side are sometimes followed by lower temperature. At our station it was different: for more than half the year, calculated in hours, the wind blew from the southwest with an average force of about 15 meters a second, consequently approaching the limit at which the meteorologist speaks of a gale. If account be taken only of autumn and winter the wind was still strong. During these storms the mean temperature was more than 2° below normal, while during a calm it was above normal.

No words can describe the impression made by these hurricanes accompanied by severe cold. It was impossible to stay out of doors, and it was absolutely impossible to walk against the wind. The air was dense with fine whirling snow, so that nothing could be seen ahead, and it was sometimes a perilous undertaking to attempt even by creeping to reach our magnetic observatory situated just a few hundred meters away. Through the friction of the fine grains of ice against one another the air became saturated with electricity, so that sparks of St. Elmo's fire were to be seen even on our clothing. The stronger the wind, the lower the temperature sank. This type of weather completely dominated the climate at our station during the greater part of the year. Bodman's experimental and mathematical studies of its physiological effects compared with the published observations of other expeditions show that hardly ever has a wintering party had to endure such a really severe climate as we during our first winter.

In the very beginning it seemed likely that these storms in one way or another were connected with the enormous difference in temperature that exists between the very cold inland ice and the adjacent sea with its low air pressure. It is not the normal temperature of the region that appears in our tables, but the cold brought from the interior of the continent. This is an important conclusion, but it must be admitted that when we returned home there were still many facts that seemed to controvert it: Why did the climate at the other Antarctic stations, even though stormy and cold, show this type so much less distinctly and why did these southerly storms, if they were down-blowing winds, not show the characteristics of föhns, i.e. why were they not relatively warm instead of cold? Furthermore, as has already been

mentioned, the climate at the border of the inland ice in Greenland is of an entirely opposite type.

These contrasts can hardly be fully explained until detailed meteorological studies shall have been made of the higher strata of the air in these regions. The correctness of the nucleus of the idea may now be proved by the results obtained by the Australasian Antarctic Expedition under Sir Douglas Mawson. At about the Antarctic Circle and the longitude of Tasmania, Mawson found a climate of the same character as at Snow Hill Island (on the eastern side of the Graham Land peninsula) but still more pronounced, incomparably the severest hitherto known on the earth. The mean temperature at this latitude was about –18°, one of the lowest known; but this temperature was accompanied and characterized by a strength of wind whose equal has nowhere been met with. The velocity of the wind for the entire period of observation, according to the preliminary records of the expedition, was of whole gale force, amounting to 22 meters a second; and it was this hurricane that, plunging almost continuously from the south and south-southeast down the sides of the inland ice, caused the extremely low temperatures. Here there is no doubt about the cause: It must be the contrast between the high and completely ice-covered and ice-cold land and the deep barometric trough over the relatively warm sea in the north that caused this terrific downward draft of wind. The contrast between the storms at Mawson's station and the cold and calm at Amundsen's station can perhaps be explained by the observation of the Swedish meteorologist J. W. Sandström, that it is not the contrasting temperature in itself but this together with a great difference in altitude that causes the severest storms; at Amundsen's station there was no high land in the vicinity. The temperature on the inland ice must be exceedingly low, as the winds in spite of their downward motion are so cold. At any rate, at Snow Hill our expedition during the winter lived in a land whose climate during about half the time was, so to say, a normal polar coast climate, and during the other half was an exceedingly cold ice climate governed by blizzards from the inland ice; Mawson's station in Wilkes Land, on the other hand, belongs permanently to the latter type.

With the exception of the conclusions that can be drawn from the observations mentioned, we know, in spite of the journeys of Amundsen and the British, little more about the climate of the ice interior of the Antarctic than about that of Greenland. At the south pole itself the temperature during the first summer month, December, may lie between –25° and –30°, but this is at an altitude of nearly 3000 meters. Reduced to sea level, according to Mohn's calculation, this temperature during the warmest month would be –10°. Regarding the winter, all that is known is that it is exceedingly cold, and every-

thing indicates that the south pole or its vicinity is the coldest spot on the earth.[8]

In order to understand the influence of the inland ice on the climate it is desirable that we know its own temperature at different seasons; but about this also very little is known. The only series of observations covering a year or more from a truly polar area of accumulation known to me is the one I carried out at Snow Hill at the edge of the ice mass covering this island.[9] It was found that at the depth of one meter the ice in summer time was nearly 3° colder than ice-free ground at the same depth; in winter, on the contrary, it was 1° to 1½° warmer. The annual average is about the same, though the ice is somewhat colder than the ground. The temperature of the ice consequently has the same characteristics as the inland ice type of climate. During summer the inland ice has a strong cooling effect, much more so than the ice-covered sea. In winter also it has a cooling effect in comparison with the sea ice; and, as the temperature above the ice does not seem to be so low as in real continental areas, e.g. eastern Siberia, these somewhat higher temperatures may largely be due to the winds which it causes. During calm weather and strong radiation the temperature, according to the experiences at Amundsen's station, may in the interior of the Antarctic inland ice sink almost as low as in Siberia.

It is this inland-ice type of climate that gives its character to the *whole* Antarctic region, not only on land but also for some distance out on the surrounding seas. The storms against which Mawson and we had to struggle may only locally have such terrific force; but the immense masses of extremely cold air which they bring along must exert an influence on the whole region in their path, because later they are carried by new winds, local or general, along the coasts of the continents and then cause the characteristic low temperatures. This is natural for winter; but it is perhaps not entirely evident how the still more pronounced low summer temperature is brought about, since at that season at Snow Hill the blizzards were considerably weaker. Mawson's observations show, however, that they can be quite violent even in summer, and it is well known that summer is the time when the low temperature of the ice makes itself felt most.

The reason why the climatic type which in greater or less degree seems to prevail everywhere on the coasts of the Antarctic does not seem to occur at all on the border of the Greenland ice should be touched upon here, even if it cannot be completely elucidated. In the coastal belt of Greenland, as we have seen, there prevails either a distinct maritime climate or else a continental climate, and the winds

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[8] Simpson on the basis of the observations of Amundsen and Scott calculates the following values for the south pole, reduced to sea level: December, 1911, −8.2°; January, 1912, −13.7°. Meinardus assumes −42° for July.

[9] For the winter an unusually fine series of observations has been carried out by J. P. Koch at the station mentioned above on the Greenland ice cap.

from the interior of the inland ice, which are fairly frequent, appear there as typical föhns. The fundamental cause may in some way be connected with the much smaller extent of the ice and with the further fact, perhaps, that Greenland is relatively narrower and on both sides is bordered by fairly warm seas. This is, however, one of the major problems of climatology, and nowhere are thorough meteorological observations according to modern methods more important than here.

Summary

If we here wish to summarize our results with regard to temperature conditions in the Polar Regions, we can first of all state that the annual mean of the real inner Polar Regions is everywhere probably very low. They are unquestionably the "coldest regions on earth." However, although the winters are very cold, this statement does not apply to these regions with regard to the coldest months of the year or to minimum temperatures in general, which we now know to be still lower, for example, in the interior of eastern Siberia. But Amundsen's experience shows that it is not impossible that wind-protected valley depressions may be found in the Antarctic Continent where the temperature drops as low as in Siberia. On the other hand, the mean summer temperatures in the Polar Regions are decidedly the lowest on earth, and the temperature range in summer, however noticeable it may be for living beings because it extends from above to below the freezing point, is as a rule not excessively large in the different regions. As precisely mean summer temperatures are employed to delimit the Polar Regions no high mean temperatures should theoretically be found in these regions, and so far they have not been proved. Various observations, however, point to the fact that purely locally in the interior of certain ice-free Arctic islands, whose surroundings are unquestionably polar, the mean summer temperature can exceed +10° C.

The explanation for all these characteristic features of the polar climate we find in the fact that here, in contrast to other regions of the earth, the solar climate is less influenced by land and sea than by ice. Two different main types may be distinguished, namely (1) climates primarily under the influence of the land ice and (2) those whose most important features result from the influence of a more or less ice-covered sea. The *land-ice climate* prevails, with the exception of a number of small advanced islands off the northern end of Graham Land, over the whole Antarctic Continent and over Greenland as far as its inland ice extends, and it is characterized, in addition to cold winters, by especially low summer and autumn temperatures. The second type, the *drift-ice climate*, varies greatly in character according to the nature of the ice cover of the sea. If the sea ice remains firm during the winter,

the influence of the water does not make itself felt to a great extent and even far from land a very cold winter ensues, although not as cold as in the otherwise only half-Arctic continental climate of Siberia. If, on the other hand, the sea remains open for a longer period or is only covered by drifting ice floes, a milder winter ensues, although, to be sure, in many regions it is characterized by large irregular oscillations between severe cold and mild weather, oscillations caused by the alternate influence of land ice and open water.

The effect of large unglaciated land areas on the climate is to tend to produce very cold winters and relatively warm summers. Now, where the summer temperature exceeds the mean of about (but not exactly) 10° C., with which we delimit the Polar Regions, we prefer in our classification to assign these large transition regions of the northern continents, in spite of their low annual means, to the temperate zone. The islands of the American Arctic Archipelago have, so far as we know, a true polar climate; but just in the interior of these for the most part completely ice-free islands, as well as in similar land areas on the west and north coast of Greenland, it is not improbable that the summer temperatures reach a height greater than elsewhere in the Polar Regions, so that theirs is really a case of a polar land climate—a type certainly rare elsewhere in the Arctic.

All in all, the map of the Polar Regions presents a very checkered picture of the distribution of temperature; different regions, even though close to each other, can be quite different. We know much less about the conditions of precipitation but probably they are much more uniform; and usually most polar regions have relatively little precipitation. This question, however, will be touched upon in the following chapter. On the other hand the wind conditions, next to temperature the most important of the climatic factors in the Polar Regions, again show great contrasts. Where heavy winds are combined with intense cold, as especially on the coasts of the Antarctic Continent, a climate results that excludes nearly all life and in severity is nowhere surpassed on the earth. In other extensive regions, on the other hand, where in winter the temperature is low and the air calm and in summer insolation warms the ground and the lowermost strata of the air to a high degree, the polar climate in no way prohibits human life and settlement; and it is only through its indirect consequence in forming ice and limiting vegetation that it here becomes hostile to civilization.

We shall now proceed to an account of these aspects of polar nature.

CHAPTER II

THE ICE IN THE POLAR REGIONS

The Occurrence of Land Ice on the Globe and Its Division into Different Types

As generally known and as discussed in the preceding chapter, climate is the fundamental cause of the differences that distinguish the Polar Regions from other parts of the earth. But the feature which primarily characterizes polar nature and which differentiates the various parts of the Polar Regions one from another is the perpetual ice; and this should therefore now be discussed. In the Polar Regions proper there are also ice-free areas, as will presently be shown, but these are rather insignificant in relation to the total surface of the Arctic and Antarctic, and indeed the boundary of the distribution of perpetual ice even outside of the high mountains constitutes a good limit for the whole Polar Regions.[1] Large areas on the Arctic coasts of the northern continents, which in winter are colder than many polar lands, become transition regions because of the fact that ice and snow disappear during summer.

Perpetual ice is, however, not limited to the Polar Regions; as known, it is to be found also in many high mountain regions in various parts of the earth. It was naturally in these mountain regions that ice and its forms were first studied, and too much of our system of classification of ice forms is still derived from them. First, this classification will be touched upon in order to make clear, by a comparison between the various types and their distribution, the really characteristic features of the polar ice and thus of polar nature; and then in the same way we shall endeavor to show the features which chiefly cause the fundamental differences among various polar regions.

The most usual classification of ice forms is that of the famous Swiss scientist Albert Heim, who distinguishes four types: viz. glacial, or alpine; Norwegian; Alaskan; and Greenlandic, or inland ice. The alpine ice form consists of a true valley glacier with a relatively little-developed catchment basin, while the Norwegian type forms cake-shaped plateau glaciers with short valley arms. Next comes, in temperate regions, the relatively rare Alaskan type, in which

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[1] The most important exception to this condition occurs in the western part of the American Arctic Archipelago, which according to Stefansson is almost entirely ice-free. Why this is so cannot be determined with certainty from the observations available at present. Probably precipitation is very slight and temperatures inland are higher than has hitherto been assumed (see also, below, p. 37).

the ice, divided in the mountains into branches, forms at the foot of the mountains a single extended sheet. Besides these, in the coldest regions of the earth, there is the real polar type of the inland ice which, as a continuous sheet with a smooth surface, covers mountains and valleys. It was thought that the more differentiated ice forms occurring in marginal regions of the inland ice or in such polar countries as lack a real continuous ice sheet could be classified with one or another of the three first-mentioned types.

However, it soon became evident that this classification is not quite suitable if one begins with conditions in the Polar Regions, which is evidently the proper way to proceed. The German polar explorer Erich von Drygalski has endeavored, so to say, to adjust the classification to the Polar Regions by changing somewhat the general definitions. Starting from the differences between the areas of accumulation of the ice and its zone of depletion, he defines the alpine type as comprising ice masses that, within both these parts of its area, are divided into separate branches and basins, whereas its extreme opposite, the inland ice, is characterized by an enormously large uniform mass of accumulation. Of the two other types, the Norwegian sends out isolated valley glaciers from a closed area of accumulation (a "highland ice-cake"), while, on the other hand, in the Alaskan type the separated ice branches of a high mountain massif flow together at the foot of the mountain to form a single area of depletion. Theoretically such a system should comprise all the ice forms of the earth; but as a matter of fact this terminology is entirely insufficient to clarify the differences between the widely varying ice types of such importance especially in the Polar Regions.

Other attempts to classify glaciers, as is well known, have also been made. W. H. Hobbs makes a sharp distinction between mountain glaciers, where ice-free parts rise above the ice, and polar glaciers, where this is as a rule not the case; each group is then subdivided. Priestley has essayed another detailed and interesting classification in the report on the British *Terra Nova* expedition. Other systems also go far in their detailed classification, but none of them has been generally accepted. The problem is of a certain importance, however, and deserves to be carried further. The points which primarily interest us about a glacier are the shape of the ice mass, its motion, and the work it accomplishes. Again, these factors evidently depend partly on the mass of the ice, partly on the shape of the substratum. It therefore seems proper to base our classification on these two elements. The landforms may in themselves be the same in different parts of the earth. The difference between the polar glaciers proper and those in temperate or equatorial mountain regions is to be found in the other main factor, the mass of the ice: only in the Polar Regions does this become so extensive as to be independent of the landforms and only

there is the bulk of the ice found outside of the mountains proper. Starting from these viewpoints, without here having the opportunity to go into details, glaciers may be divided into the following main types, which will be explained in a number of descriptions and illustrations.

A Highland Glaciers

I Ice shape and motion everywhere dependent on the terrain.

1. Between the different catchment basins dominating ice-free ridges protrude; outlet in well-developed valley glaciers (*valley glacier, or alpine type.*)
2. A closed catchment basin on level plateaus (*plateau glacier, or Norwegian type*).
3. Ice masses with catchment basin and valley glaciers of alpine type flow together on the level ground at the foot of the mountain, forming a continuous ice field (*piedmont glacier, or Alaskan type*).

II Ice form and motion independent or partly independent of the landforms.

4. The landforms are covered by the ice but appear distinctly below and through the ice; outlet glaciers in comparison with the mass of the catchment basin (*nivation glacier, or Spitsbergen type*).
5. The ice hides all landforms (*inland ice, or Greenlandic type*).

B Lowland Glaciers (in which the area of deposition and area of dissipation are one and the same).

6. The ice follows the foot of the mountain in a band (*ice-foot, or,* according to Priestley, *snowdrift glacier*).
7. Ice formed mainly on the spot covers both the lowland and shallow parts of the sea (*shelf ice*).

In the Polar Regions all these types may be expected to occur. The three first-mentioned, Hobbs's mountain glaciers, also occur in temperate mountain regions; especially does type No. 1, which is also by far the most common. Type No. 4 forms a transition group which occurs in much-dissected mountain regions of polar character. The three last-mentioned types are the polar glaciers proper, which can never occur in temperate regions.

The most common and best-known type is the alpine glacier. At a great altitude in a rugged mountain range snow and ice are collected, not on the highest peaks or summits, where they cannot remain on account of the wind, but on the slopes in depressions and niches which the ice has partly formed for itself. These ice-holding catchment basins are separated by wild mountain ridges whose dark walls rise abruptly above the ice. The ice flows downward through the valleys, which it also deepens, and, because it melts, ends before it reaches the lowland. Only in regions with a polar climate or their vicinity, where the summer is very cool, do these glaciers reach the sea. The well-known Jökelbräen on the north coast of Norway forms certainly a more apparent than real example of this condition; outside the polar circles this is to be found only in the northernmost and southernmost

parts of America and on some oceanic islands. In such regions with cold summers and very heavy precipitation on the borders of the Polar Regions, at places where a plain extends between the foot of the mountain and the sea, the ice branches can occasionally unite again to form a continuous body on the piedmont plain—a glacier of Alaskan type.

Glaciers of true alpine type are of course also to be found in the Polar Regions, most often along the coasts of mountain ranges that are not too strongly glaciated or too deeply dissected by valleys. Here belong, for instance, large parts of the coasts of Greenland and Spitsbergen (see Fig. 3). Of these coasts it can be said with a certain amount of truth that they resemble the highest part of the Alps or other high mountain regions submerged to the level of the sea.

This, however, cannot be said of the Polar Regions, where the ice for climatic or other reasons collects in still greater masses, even if the very shape of the mountains is distinctly alpine. A good example of such an area occurs in the interior parts of northwestern Spitsbergen. To be sure here also numerous mountain peaks—nunataks, as they are called by the Eskimos—rise above the ice. But the continuous ice-free ridges that give individuality and limits to the glaciers in the Alps are lacking or play a minor part. Instead the ice climbs all valley slopes, fills all passes, and at both higher and lower levels coalesces to fields, ice sheets on a small scale, which are comparatively independent of the shape of the substratum. At numerous places the ice flows from a valley through a pass into another valley. This ice form grows still more distinct and characteristic in certain parts of the Antarctic Regions, as in the South Shetland Islands and along the northwestern side of Graham Land. The whole country is there covered by immense ice masses which, however, do not wholly conceal but only outline the shape of the land underneath and which extend beyond the edge of the highland and conceal the strip of lowland that may occur at its foot. Only scattered peaks and precipitous walls on the lee side of the prevailing winds protrude from the blue-white ice cover. It can rightly be said that in these areas a transition form is to be found between the alpine and Alaskan types, on the one hand, and the inland ice, the polar type, on the other. This transition form is characterized by the fact that the shape and motion of the ice on account of its great mass is not strictly bound by the terrain and that even in the catchment area fairly great uniformity is to be found. It is evident that this ice form should have its own name, and I have therefore proposed to call it the Spitsbergen type (Fig. 5). Whether in full development it ever occurs in temperate regions cannot be said with certainty; but as far as my experiences go I consider it probable that the immense ice fields in the cordilleras of southern Patagonia belong to this type.

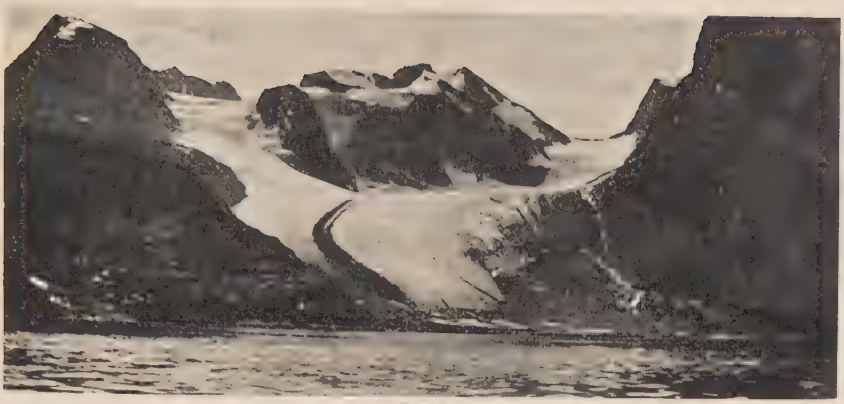

FIG. 3

FIG. 4

FIG. 5

FIG. 3—Valley glacier, or alpine type, in one of the fiords of western Greenland. South Ström Fiord. (Photograph by the author.)

FIG. 4—Glacier of a type transitional between the alpine and Spitsbergen types. Hope Bay, Antarctic Sound, West Antarctica. (Photograph from the author.)

FIG. 5—Ice mantle of Spitsbergen type, grading into inland ice. Northwestern coast of West Antarctica, at Bransfield Strait. (Photograph from the Swedish Antarctic Expedition.)

The Types of Continental Ice: Inland Ice and Shelf Ice and the Conditions of Their Formation

In a narrow mountainous land or on an island with deep valleys and steep coasts along which the ice easily flows away, the development of the ice seems never to go beyond this form. Ice masses of really continental dimensions arise only in wide highland areas where the height differences are small in comparison with the enormous extension

Fig. 6—View of the edge of the Greenland inland ice at a point where it reaches the sea, exposing only individual marginal elevations of the subjacent land. Ikerssuak Bay, east coast, latitude 65° 30′ N. (From drawing by Knudsen in *Meddelelser om Grönland*, Vol. 61, Fig. 5, opp. p. 576.)

of the catchment areas and where the ice therefore can pile up in such quantities that it at last completely conceals all landforms and coalesces all the mountains and valleys to a single apparently even sheet. The motion of the ice in this case is at least at the surface independent of the terrain, and nunataks are completely lacking or are in any case very scarce except in the marginal regions. This is what is called inland ice. No landscape on the earth can compete with it in magnificent, monotonous desolation. Even the sea has its perpetual motion and the desert its colors and varying forms, but this white plain is endless and even as a floor, except for the so-called *sastrugi*—snow ridges with sharp edges separated by deep furrows and trending in the direction of the prevailing wind. There are only two ice sheets of continental dimensions. The one is the Greenlandic, whose area is greater than all other ice fields put together except the Antarctic. The other is the continuous Antarctic ice cap, which certainly covers an area larger than Europe. In Greenland the ice mostly ends on land, where it divides into broad tongues or large valley glaciers which later at many places reach the sea and there are broken to pieces, while elsewhere outside the ice a coastal rim with its own smaller ice masses of alpine or Norwegian type is to be found. In Antarctica, on the other hand, the main body of the ice as a rule reaches out into the sea, the coastal cliffs of the subjacent land being

often distinguishable by the sharper breaks in the ice. The land itself is only seldom seen, and one can travel hundreds of kilometers along the shore without meeting a single rock or nunatak.

Also at a number of other places one can properly speak of inland ice on a smaller scale—though more as a transition to the ice domes, or "island ice" mentioned below—especially Northeast Land in Spitsbergen and possibly also Franz Josef Land, where, however, the level surface of the ice cover is partly due to the evenness of the land itself; but outside the Polar Regions this ice form does not occur at the present time. In order to determine its relation to the other ice forms it is necessary to find out to which glacier types in the temperate mountain regions it most closely corresponds and what is its appearance on smaller islands and other limited areas in the Polar Regions.

As regards the first question it is only natural that the glaciers which outside the Polar Regions most closely correspond to the inland ice are to be found in semipolar mountain regions whose extent is large as compared with their relief. Such an area is met with in the characteristic mountain plateaus of Norway, where also the largest glaciers of Europe are to be found—immense, nearly level, or somewhat dome-shaped ice bodies with relatively few nunataks. Instead of being enclosed by mountain masses as in the Alps they rise above their surroundings and, like inland ice, discharge in all directions by short tongue-and-valley glaciers. This is the highland ice of the Norwegian type (Fig. 7). Formations of exactly the same kind but of much larger dimensions also occur in Iceland, and if only their shape is considered they can rightly be regarded as small ice sheets. The essential difference from this type is to be found in the fact that the "Norwegian glaciers" have acquired their shape in accordance with the substratum and not in spite of it, as with the inland ice; they are strictly bound to high plateaus, and they probably have no motion independent of the landforms that is worth mentioning. Ice plateaus of the same kind are also common in the Polar Regions, where, as will be shown in a later chapter, the plateau form is especially characteristic in several mountain regions; they are frequently met with in the coastal belt of Greenland and even in Franz Josef Land and Spitsbergen. The Spitsbergen type described above also often approaches this one. It is chiefly characterized by the fact that individual parts of many of the types occurring in temperate regions, in a climate favorable for the formation of ice, expand and coalesce with adjacent ice fields to form single masses.

Also on smaller, more or less plateau-shaped islands cake-shaped ice masses are occasionally met with in the Polar Regions themselves, which are to be counted as belonging to this type. In the innermost Polar Regions, above all in the Antarctic, these occasion-

ally expand over entire islands and cover them so completely that almost no part of the substratum is to be seen, giving them the appearance of dome-shaped islands of pure ice. To this type belong some northern islands whose mere names suggest their appearance; for instance White Island (Giles Land), east of Spitsbergen, and Hvidtenland (White Land), discovered by Nansen. But the type is much more common in the Antarctic, where Snow Hill Island, on which the Swedish winter station was situated, forms an excellent example. In these cases one would expect inland ice on a small scale without distinction between area of nourishment and area of depletion. But, in fact, the whole ice body corresponds to the marginal belt of the inland ice, while the immense interior ice plains of course are lacking and the substrata, especially the coastal cliffs, clearly reflect themselves in the shape of the ice. These glaciers also, not being included in the classification given above, evidently deserve their own name; they might well be called *ice domes* or ice calottes (*ice caps*, or, according to Priestley, *island ice*).

All the most important of the ice forms that have long been known from the Arctic and temperate regions have perhaps now been mentioned. A few types of glaciers, however, especially in the Antarctic Regions, are to be found which play a great rôle and immediately strike the eye, namely those included above under the name of lowland glaciers. The one type consists of continuous bands of ice, fairly narrow and limited on the outer side by a perpendicular wall, bands which for long distances near the shore follow the mountain walls as they slope towards the sea. They receive no supply from the interior but are formed from snow that falls on the spot or is brought down by the wind from the slopes. The latter form of origin gave rise to the name "snowdrift glaciers," while according to their appearance they are designated by the terms "ice foot" or "ice-foot glaciers."

The other far more important type has hitherto been definitely known only in the Antarctic Regions. Early seafarers, especially James Ross, found their way towards the Antarctic Continent shut off for long distances by a perpendicular ice wall rising out of the sea, an ice wall varying in height from a few meters to 50–80 meters. Only in recent times have attempts been made to proceed over this wall on foot. On its summit one stands on a practically flat plain of ice over which one may travel for miles and miles toward land without rising more than a few meters. The surface of this ice form reminds one of the inland ice, which, if possible, it surpasses in desolate monotony. The most extensive ice fields of this type occur in enclosed and relatively shallow bays or sounds of the Antarctic Continent. For this ice form the name "shelf ice" has been proposed in order to indicate that as a rule it is bound to the shallow submarine plateau, the shelf, which borders

FIG. 7

FIG. 8

FIG. 7—Plateau ice of Norwegian type. Jostedalsbräen, seen from the high plateau at its south-eastern edge. (Photograph by the author.)

FIG. 8—Cliff edge of the ice dome, or island ice, on Snow Hill Island, West Antarctica. (Photograph from the author.)

the land.[2] It was over such an ice field, in area at least comparable with Sweden but possibly still larger, that Shackleton, Scott, and Amundsen began their journeys towards the south pole. Another shelf ice covers the interior part of Weddell Sea, the embayment (or strait?), which limits the Atlantic Ocean to the south (see Fig. 9). A smaller field of this type was discovered by us during a sledge expedition, and on it I spent several weeks. The actual extent of all the shelf ice on the earth is still unknown; but it is certain that next to the inland ice it occupies the largest area of all the glacier types, an area possibly as large as all the others together with the exception of the inland ice. It should therefore be rated high in importance, but its mode of formation is still disputed. Several modern explorers at first compared this ice form with the Alaskan glacier type, where gigantic outlet tongues were supposed to be connected with the interior glaciers. This view, however, can hardly be correct: it can be shown that at least all the ice now above the water is formed from snow that has fallen outside the highland on the sea ice or possibly on a low foreland. Consequently no distinction exists between the area of nourishment and the area of depletion. Here as well as in the case of the ice-foot ice it must be left for future study to determine whether the shelf ice, as Priestley assumes for the Ross Barrier, in certain cases has a core of glacier ice, originating from projected ice tongues and originally compacted from sea ice, or possibly, as von Drygalski in similar cases has supposed, of welded icebergs. As for myself, I early held the opinion, later accepted by all investigators who have studied the shelf ice in greater detail, that it is mainly formed of snow that falls on the sea ice and gradually grows in thickness and presses down its substratum. It would apparently grow indefinitely in thickness if it did not move towards the open sea and if it were not to some extent subjected to melting from beneath. The conditions for its formation are consequently that the annual accumulation of snow at sea level on a substratum of ice[3] be greater than the melting; further that the ice formation take place in a bay or other enclosed area protected against the stronger waves and preferably on a shallow continental shelf where the ice here and there can rest on the sea bottom; and finally that the temperature of this water down to the lowest parts of the ice be essentially below 0° C. or in any case so low that melting from beneath becomes very insignificant. All these conditions prevail in the region where I learned to know this ice form.

Some earlier investigators have defined the shelf ice as "floating inland ice," a name, however, that is very unsuitable: this ice forma-

[2] Another name sometimes used for this ice form is "barrier ice." I myself at first used the name "ice terrace."

[3] Accumulation on ice or snow, as is shown by our measurements, takes place much more easily than on bare ground.

tion cannot be called inland ice, and it may only partly be afloat. Under the same name also another peculiar formation, reminding one of the shelf ice, was described by J. P. Koch and Alfred Wegener in the Arctic from Jökelbugt (Glacier Bay) on the east coast of Greenland. An even or undulating ice field, several thousand square kilometers in extent, partly crossed by large crevasses, here lies enclosed between a

FIG. 9—Inland ice with shelf ice in front of it. Luitpold Land, south coast of Weddell Sea. (From Filchner, *Zeitschr. Gesell. für Erdkunde zu Berlin*, 1913, Fig. 1.)

string of islands and the mainland covered by inland ice. The ice rests partly on the sea bottom but is partly floating; and on its outer edge it almost imperceptibly merges into the sea ice. In most of these particulars it resembles the shelf ice, but the conditions of its formation and existence as well as its dimensions are apparently quite different: the melting from above and from beneath is certainly greater here than the annual growth by accumulation of snow; and it may therefore be doubted whether to any great extent it has been formed on the spot.

In conclusion, we may now try to arrive at an understanding of the conditions of formation, development, and waning of the inland ice. This problem is of particular importance to all who live in glaciated regions in order to explain what changes in various respects the land underwent when it was covered by an ice sheet as well as later when this disappeared. It may appear quite natural that a highland in the

Polar Regions with fairly heavy precipitation should become covered by ice; and it is perhaps evident that on a narrow mountain chain like the Scandinavian the existing plateau glaciers of Norwegian type would expand considerably in a lowering temperature. The case, however, is not so simple. The difficulty begins as soon as we try to explain why an area like Greenland, whose summer on the west coast and especially in the southern part is rather mild, should be covered by such enormous ice masses. In spite of the exceedingly heavy precipitation the high coastal mountains of southern Greenland are but partly covered with ice, while the continental climate, which apparently should prevail in the interior of the country, cannot well be more favorable for the accumulation of ice than that prevailing nearer the coast. The existing climate, therefore, can hardly explain the existence of the inland ice. Some investigators have assumed that the ice sheet is largely derived from the mountains of eastern Greenland, but recent investigations do not support this view. On the contrary it is probable that the ice has expanded from the north towards the south. The explanation seems largely to be that the present climate is not an ordinary continental one but is what has been characterized as a continental ice climate. With the climate of the former type the summer in the whole southern half of Greenland would be too warm for the development of inland ice. But if, on the other hand, during a colder period, a period more favorable for ice formation, such as the Glacial Epoch, glaciation of large dimensions arose first in northern Greenland and later in the highlands of southern Greenland, this very ice might have produced a considerable lowering of the summer temperature, causing its own expansion and survival even though the climate as a whole grew milder. To be sure the ice has shrunken considerably since the Ice Age; but at present it is fairly stationary in Greenland and has been so for a long time, as is evident among other things from the strong weathering of the rocks up to the very ice front (see Fig. 10). On the whole, the inland ice in southern Greenland according to this view is to be regarded as a relict ice, a remains from an earlier colder period.

Another problem, which is no easier to answer, is, How is it possible for an ice mass uninterruptedly to cover a large continent? In such a cold center a barometric high-pressure area must be assumed to arise, accompanied by centrifugal winds and a descending dry air current which would cause only slight precipitation. One would therefore expect the ice surface not to become higher but, rather, to become lower toward the center; and from this premise A. E. Nordenskiöld was correct in advancing his hypothesis that perhaps ice-free areas were to be found in the interior of Greenland. This is now known not to be the case, but if it be argued that Greenland is too narrow and too high for a greater decrease of the ice masses in its interior to occur in this way, the same cannot be said of the Antarctic Continent.

Even now we cannot be sure that such ice-free areas do not exist, for the parts of the continent that can really be called central have not yet been reached. Surprising observations may still be made there; and in any case it seems as if the surface of the ice, now that the margin of the plateau has been reached at altitudes of 2000–3000 meters, would not be much higher towards the real interior. Furthermore, Amundsen met ice-free mountain peaks at what is probably quite a distance from the immediate edge of the continent. It is, however, not likely that very large ice-free areas would be found there. Besides the theoretically dry air and the insignificant precipitation in the interior of the ice areas there are also other reasons which would tend to prevent the ice cover from reaching great thickness: disregarding loss by evaporation and by its outward flow there is the loss caused by the fact that the constantly outblowing winds at low temperatures carry away masses of drifting snow. These enormous masses of fine-grained snow crystals, which at the slightest wind move along the ground and frequently entirely fill the air, are a feature that all explorers on the inland ice and on the shelf ice have described and have had to overcome.

In order to explain why, nevertheless, such large quantities of ice actually occur in the interior one may resort to two hypotheses, which may possibly not exclude each other but rather may tend to confirm each other on certain occasions. According to one,[4] the high-pressure area with its dry air may not extend upwards especially far, at most about 2000 meters; above this limit there may be the belt where the pressure in the vicinity of the south pole is lower than farther out and where moist air flows in towards the pole, on account of which also the precipitation here would be relatively large. Amundsen's observations at the south pole seem to indicate that conditions of this kind at least sometimes occur there; regarding Greenland the problem seems to be more doubtful. According to another view, the moisture which conditions the growth of the ice may be derived directly from the upper strata of the air. Hobbs has developed this view further. He proceeds from the fact that in Greenland as well as in Antarctica an anticyclone with high pressure and outflowing winds lies over the high inland ice, where, however, the air is not, as in other anticyclonic regions, dry but relatively moist, finding in the cirrus clouds an adequate source of supply for this moisture. This moisture is then supposed to have been precipitated mainly as hoarfrost ("frost snow") by extreme cooling at the very surface of the ice. It is probable that a considerable condensation of this kind took place at the Swedish winter station of Snow Hill, and several investigators have latterly shown that precipitation of frost is of great importance in certain

[4] Developed by Wilhelm Meinardus in the scientific reports of the German Antarctic Expedition (Vol. 3: Meteorology, Part I, pp. 1–339, Berlin, 1909–1911).

semipolar mountain regions, e.g. in Norway.[5] However, these results cannot be directly applied to the inland ice.[6] A better idea of these interesting problems could perhaps be obtained through studies of the nature of the ice grains in the topmost layers. At Snow Hill I frequently observed layers of comparatively large well-developed ice crystals which probably are related to some kind of sublimation or precipitation from the air. It is thus perhaps the case that the growth of the ice to some extent takes place through hoarfrost, which is precipitated on the surface or between the snow grains in the loose uppermost layer. The best observations at hand regarding the nature of the ice in the interior of an ice sheet are derived from J. P. Koch's crossing of Greenland. Although he himself does not enter upon these problems there are in his description several things that might indicate a similar solution, namely, that ice might increase in mass, even if not in thickness, through precipitation of moisture from air that circulates among the snow grains.

Ice-Free Areas in the Polar Regions

Another very interesting problem will be discussed in this connection. In what precedes we have attempted to explain the formation of the ice; but now let us ask, Why do such large ice-free areas occur in the interior Arctic Regions? Even if these can mostly be explained by the fact that the summer at sea level and on the lower land areas is not cold enough to permit the winter's snow to remain, why is it that there are to be found in adjacent regions areas with extreme differences in the ice covering?

These questions cannot be answered at present. The absence of ice on the northern coastal margin of Asia and America may be explained by the immediate connections with these continents that become heated in summer time; but the large ice-free areas in Grinnell

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[5] A distinct zone of hoarfrost during the winter has been found here by Hans Ahlmann in the highest mountains of the Lofoten Islands, above 700 meters altitude. The feature has been studied in the Swedish mountains by J. W. Sandström.

[6] The nourishment of ice sheets is also held by G. C. Simpson (sci. results British Antarctic Expedition, 1910–1913: Meteorology, Vol. 1, Calcutta, 1919, p. 268; restated in same series: Glaciology, by C. S. Wright and R. E. Priestley, London, 1922, p. 9) to take place through snowfall in the anticyclone which is developed above the ice and which is held to be permanent, but his view differs somewhat from that of Hobbs. The air blowing out on the dome-shaped ice surface is very cold because of radiation and contact with the ice. On the normal fine-weather conditions are superimposed a series of centrifugal pressure waves. These waves alter the surface pressure distribution and cause air motion which is frequently accompanied by forced ascending currents. The very cold surface air is forced upward in these currents and is rapidly cooled further in the ascent, so that the water contained is precipitated as snow.

According to another recent view (E. van Everdingen: Gibt es stationäre glaziale Antizyklonen?, pp. 18–19, "Köppen-Heft," suppl. to Sept., 1926, number of *Annal. der Hydrogr. und Marit. Meteorol.*; F. M. Exner: review of W. H. Hobbs's "The Glacial Anticyclones," *Meteorol. Zeitschr.*, Vol. 43, 1926, pp. 510–512) the glacial anticyclones are not permanent but change their positions. When the whole anticyclone is removed relatively warm air from the sea can cover the ice sheet and even during its rise cause some precipitation. On restoration of anticyclonic pressure by air currents at high levels the cyclonic air will be cooled off so as to give up its moisture.—Transl. Note.

Land and Grant Land and elsewhere in the American Archipelago must be explained by the insignificant precipitation that occurs at present and also certainly occurred during the Ice Age. J. W. Sandström's investigations seem to indicate that, on the whole, the air circulation over a highland, especially if it is ice-covered, is much stronger than over a lowland with the same temperature conditions. This condition surely plays a great rôle. It would seem as if in the Polar Regions the situation in relation to the low-pressure areas may not itself determine the quantity of snow; with the exception of southern Greenland, where precipitation is great, the exceptional development of ice in Greenland, for instance, cannot be explained in this way. On account of the low temperatures prevailing in these regions, on the other hand, heavy precipitation can be brought about largely by extraordinarily strong air circulation, for which there is no reason in the ice-poor land areas mentioned.

Explanations of this kind, however, cannot be applied to regions in which areas that are almost free of ice border on such as are completely ice-covered. In Spitsbergen, for instance, the plateau areas of Mesozoic sandstones and slates on Ice Fiord and Bell Sound belong to the former type in spite of the fact that the precipitation on the west coast should be heavy, while the Archean and Hekla Hoek areas for the most part are entirely snow-covered. In the Antarctic also the islands of younger sedimentary rocks, for instance Seymour Island and Snow Hill Island, appear to be somewhat less ice-covered than the others—a rule which also holds for the smaller islands around Spitsbergen. A remarkable example is also Jameson Land in east Greenland, composed of sandstone, gravel, and sand, which, although reaching an altitude in its northern part of nearly 1000 meters, is entirely ice-free. This cannot to my mind be fully explained by its somewhat lower position relative to the eastern heavily ice-covered marginal range of Archean rocks. It seems possible that the topography of such sedimentary plateau areas is less suitable for the accumulation of snow; but it is difficult to understand why this should be the case. The fact that the oldest, hardest, and most varied rocks are more thickly ice-covered is perhaps explained by the frequent occurrence of fissures and other hollows in which the ice easily remains. On the other hand it has been suggested that the absence of ice in younger sedimentary areas or on gravel plateaus may be due to the composition of the rock or its capacity to receive and retain the heat.[7]

It is also difficult to explain why the higher mountains on the west coast of Greenland are so free from ice. The precipitation cannot possibly be less than in the interior, and everything consequently indicates that the heavy glaciation inland is connected with some

[7] Direct investigations made in Oslo by Professor Vegard have, however, given negative results. The greater or less porosity of the rock might possibly have some bearing.

conditions in the interior, prevailing at present or during the Ice Age, that differ from those known on the west coast.

Ground Ice

A feature particularly characteristic of such ice-free areas with polar climate is the permanently frozen ground. It was once held that such frozen ground occurs wherever the annual mean temperature sinks below freezing point; but other conditions also, especially the thickness of the snow cover during the winter, influence its presence; and, as a rule, it is first met where the mean temperature is a few degrees below 0° C. In true polar regions, as well as in areas of winter cold like Siberia, it may attain a considerable thickness; in Spitsbergen perhaps as much as 300 meters, according to Bertil Högbom. More such studies of the nature and distribution of frozen ground are needed as those of Werenskiold on Spitsbergen, Leffingwell on Alaska, and Shostakovich on Siberia. Permanently frozen ground should be distinguished from the layers of pure ice which here and there in the Polar Regions or adjacent belts are to be found below a layer of earth or, as in Alaska and Siberia, almost directly beneath the vegetation; such ice plays a great rôle, especially on the New Siberian Islands.

Summary

Thus there exist regarding the ice as well as regarding the climate the greatest contrasts between different regions; and important problems concerning the relationship of ice and climate are still unsolved in the Antarctic, where practically all land is covered by ice. The same holds true for the interior of Greenland, while along the coasts of the western as well as of the eastern side even mountain massifs and high plateaus frequently are ice-free. To the west and north of Greenland the northernmost lands on the earth are, strangely enough, relatively free from ice, although they certainly cannot be regarded as lowlands.

In a later chapter, on the various natural provinces of the Polar Regions, we will return to this subject of the contrasts among different regions.

CHAPTER III

THE CAUSES AND NATURAL CONDITIONS OF THE ICE AGE AS ILLUSTRATED BY POLAR NATURE TODAY

The Ice Age and Its Characteristics

The preceding chapter dealt with the present extent, distribution, and mode of formation of ice in the Polar Regions. As with other aspects of nature a true perspective is gained only if we view this phenomenon in the light of the development through which it has passed. We shall now, therefore, take up the question of the Ice Age. In its elucidation the Polar Regions are, of course, of special importance. Not only do they represent the closest approximation that we now have to conditions that obtained in the Glacial Period, but the climatic changes that they have experienced also afford a clue to the interpretation of that period. In the areas where ice and cold dominate now the climate once was quite warm and the vegetation was abundant, and, conversely, the bordering regions, now temperate, once had a climate and nature similar to the Polar Regions. Let us consider the latter case more fully.

That the present temperate lands on the margin of the Arctic Regions have been subjected to a polar climate we now know to be true; but about fifty years ago it was considered one of the boldest and most sensational speculations, when science established the fact that the greater part of Europe at no very remote period was covered by an enormous sheet of ice at least as thick and continuous as is the inland ice of Greenland today. Studies in various areas have shown that as time elapsed the temperature of the Tertiary decreased and the climate grew colder. At the beginning of the Quaternary period immense masses of snow and ice collected in the Scandinavian mountains, gradually covering them and later expanding in all directions. Towards the west the ice, at least temporarily, reached the coast of England, where Scandinavian boulders have been found in till. Due south it reached to central Germany. Towards the east it once extended to the present site of Kiev in Russia. It follows that the climate from the beginning was moist and cold, even if for the moment we dismiss the problem as to whether this climatic deterioration was primary or indirect, the result possibly of the land being uplifted. At first this cold ice caused a strong condensation of the moist sea winds, and its increase was therefore rapid. Later, however, the

enormous inland ice gave rise to far different conditions of temperature, pressure, and wind over all Europe, although the actual conditions can hardly be determined as yet. Over the ice there may have been permanent high pressure, and easterly continental winds may have prevailed on the southern ice border and perhaps also in the North Sea area. The ice may have caused the lowering of the mean temperature in its vicinity, especially during the summer; but this cooling need not necessarily have contributed to its further increase, as the prevailing winds may have been rather dry. In Greenland warm and arid steppe areas are known at the very ice border, and perhaps conditions in Europe south of the great ice were similar. Still greater differences would have existed, if it can be assumed that the present low-pressure area at Iceland, due to the warm water of the Gulf Stream, then was pushed farther south. However, this question does not seem to be settled as yet. Observations in the Antarctic Regions show that an ice mass of large dimensions can cool its surroundings greatly and can exist or increase without the aid of sea winds blowing in over the ice in the lower strata of the air. The loss of ice must then evidently be replaced in some other way. In the preceding chapter the most important of the hypotheses attempting to explain the supply of moisture by the upper air currents have been touched upon. The climate during the Ice Age underwent great changes. At least during one or a few so-called interglacial epochs the ice greatly diminished, perhaps entirely disappeared, in order to expand anew for the last time, over the Baltic to beyond Berlin and to the axis of southern and central Jutland. Some 14,000 years ago the ice receded for the last time from Scandinavia. Since then conditions have on the whole resembled those now prevailing, even if some climatic changes have taken place, the temperature for a time being even higher than today.

In order to understand the causes of these enormous changes in natural conditions in so recent times, geologically speaking, it is necessary to consider the extent of the phenomenon—an isolated phenomenon must be explained in an entirely different way from a general phenomenon of world-wide distribution. It becomes more and more evident that glaciation influenced the whole globe. Besides Scandinavia the Alps were the center of an extensive glaciation, and immense ice masses covered almost the whole northern part of North America. To be sure, some students of the subject have assumed that glaciation in America was not contemporaneous in all parts but that the center moved from the west towards the east, towards Labrador and even yet ice-covered Greenland. This view seems to be based on insufficient testimony derived from the direction of striae in the relatively restricted region south and southwest of Hudson Bay, whereas evidences of the earliest and last glaciations are recorded both from

the extreme western and eastern margins of the American glaciated area. It was long held that Siberia and northern Alaska were not glaciated, but it has been found that the ice here also had a much greater extent than at present, although it was practically limited to the mountains. The remarkable "stone ice," or fossil ice, in the New Siberian Islands may be a relict from this time. Even in strictly polar regions such as Greenland and Spitsbergen the ice formerly had considerably larger extent and thickness than now.

Exactly the same conditions prevailed in the southern hemisphere. During an expedition to Tierra del Fuego in 1896 the writer found that the ice from the Cordilleras once extended eastward over all the lowland and even beyond the present Atlantic coast. Similar conditions prevailed in New Zealand and several sub-Antarctic island groups and on the Antarctic Continent; and, in spite of the fact that its ice has an extent greater than anywhere else on the earth, it was once much thicker than now, so that it filled all the large fiords and covered the land still more completely. Finally, in the equatorial belt the glaciers once extended much farther down the mountain slopes than they do today: in Peru, for instance, they covered extensive plateau regions where today even crops are grown.

Thus glaciation was a universal, not a local, affair. Everywhere on the globe, where possible, the ice in relatively late times had a greater extent than at present. But this is not all. The problem now arises as to whether the extensive distribution of the ice was practically contemporaneous all over the globe—smaller differences in time need not here be considered. This may have been the case, even if fairly convincing evidence has not yet been found. The most important thing to be determined is whether the glaciations in the north and south were synchronous. An observation made during the Swedish Antarctic Expedition, 1901–1903, may especially be mentioned. J. G. Andersson found in a deposit on Cockburn Island a rich fauna comprising, among other things, twelve species of Bryozoa which still survive. This fauna must be very young, probably dating from the beginning of the Quaternary. Of these twelve species, six still live in strictly Antarctic waters (all twelve indeed in South Georgia and other areas somewhat farther north). Four species are to be found in the Strait of Magellan, and the two remaining have so far been found only on the coasts of Australia. It may be hazardous to draw from these facts far-reaching conclusions regarding the temperature of the water; but it may have been glacial, and it must surely have been much colder than during the Tertiary. In any case this observation seems to indicate that the cold climate in the south, geologically speaking, began at the same time as the Ice Age in the north. This view is supported especially by the distribution of the ice in the equatorial zone of South America. Further studies here may decide the question.

It may be pointed out that so far not the slightest evidence exists for the supposition that the glaciation in the north was represented by an interglacial epoch in the south and vice versa. The glaciation was probably essentially contemporaneous all over the globe.[1] We can, however, go a step further and show that the change in climate from the Ice Age to the present has been about the same in the various regions. It is evident that the results of this change was more perceptible in the temperate zone than in the Polar Regions; but it should be pointed out especially that the polar regions that are now most heavily ice-covered, the Antarctic and Greenland, underwent a large increase in the ice, while the American Arctic Archipelago, whose present glaciation is insignificant, also at that time presumably had very large ice-free areas. Similarly the glaciers covered large areas in southern Patagonia, whose mountain regions in modern times are more heavily ice-covered than any other tract so far from the pole. The same holds true of some humid sub-Antarctic island groups, while northern Siberia, that is now continental in climate and has little precipitation, showed a slight increase of ice.

To this general rule there are two especially striking, at least ostensible, exceptions, namely the enormous ice sheets that once covered the now temperate parts of the continents on both sides of the North Atlantic, viz. northern Europe and northeastern North America. There are really two main problems regarding the Ice Age: one being the causes of the low temperature, and the other the causes of the enormous dimensions of the ice in the North Atlantic area.

In our attempt to acquire a conception of the climate and other geophysical conditions during the Ice Age by means of our knowledge of the Polar Regions as they now are, we should start from two chief points, namely the vegetation and the nature of the ice. The fauna and flora during the Ice Age and the conclusions to be drawn from them have been dealt with by many investigators and will not be entered upon here. It should only be stated that no too far-reaching conclusions regarding the conditions during the expansion of the ice can be drawn from the plants and animals. It is often difficult to determine from which part of the Ice Age a certain fossiliferous deposit is derived; and it is to be expected that very different climates and vegetations existed both during the different periods of the Ice Age and contemporaneously at different parts of the ice front. On the other hand, it is important to find out if possible to which type the ice in the different regions belonged. The ice in Europe must be regarded as having been typical inland ice; but its main mass, the enormous ice fields covering the lowlands in the south and the east, has no real counterpart at present, because no large continuous lowlands im-

[1] Many conditions especially point to the essential contemporaneity of the glaciations in Europe and North America.

mediately bordering upon the inland-ice area are now to be found in the Polar Regions. As the Pleistocene ice sheet of Europe was probably formed largely by snow falling on the spot, it might morphologically be compared with shelf ice, which, however, occurs in the sea and is most often formed there. True shelf ice, however, may have covered the North Sea between Norway and England, for it is difficult to imagine that this glacier formed a direct continuation of the ice of the Scandinavian mountain chain. Thus the coast here may have resembled the east side of Graham Land today, with nunataks rising out of the ice and with a sharp ice terrace marking the coast line itself.

What has been said about the European also holds for the North American ice sheet, whose central part, the so-called Keewatin Glacier on the extensive tundra west of Hudson Bay, is especially noteworthy and difficult to harmonize with the existing relief. The ice also in Tierra del Fuego and southern Patagonia may have had a character resembling an inland ice but with the same peculiar lowland type as in Europe and North America. Because of the size of these ice fields in comparison with their limited collecting area in the mountains, one can hardly speak of piedmont glaciers of the Alaskan type.

The ice cover in Spitsbergen during the Ice Age may have been an ice sheet rather independent of the topography. In Greenland the present more or less ice-free west coast belt was covered by the inland ice, out of which, however, nunataks may have arisen. Many mountain tops on the islands off this coast do not show traces of any earlier glaciation, but this does not fully disprove that the ice a long time back extended over them.[2] In northern Alaska and Siberia there were only alpine glaciers, some of which, however, were of large dimensions. On the shallow sea bottom outside the Siberian coast there possibly lay thick shelf ice. The present New Siberian Islands, which, as known, to a great extent consist of pure ice protected by the earth covering which has spread over it, may in part represent the remnant of this ice.

To summarize, therefore: The Ice Age primarily expressed itself in the spread of enormous ice masses over all the countries around the northern part of the Atlantic during part of the Quaternary. Both on the eastern and the western side the continents down to the latitudes of Amsterdam and New York were covered by ice, in the form of inland ice as well as shelf ice, to an extent which is now paralleled only in the southern hemisphere and even there only 15° to 20° of latitude closer to the pole. That is to say, coasts whose mean temperature now lies between +8° C. and 0° C. and whose warmest month shows +17° to +12°, then had the same character as areas

[2] Hobbs assumes two glaciations in this area, of which the first extended to the outer coast while the second covered only the now lower land behind it (W. H. Hobbs: The First Greenland Expedition of the University of Michigan, *Geogr. Rev.*, Vol. 17, 1927, pp. 1–35; reference on pp. 10–20).

that now have a mean annual temperature below −10° and a warmest month at the freezing point.[3] Also, in all other parts of the earth the ice showed a strong tendency to spread, although the extent was nowhere especially large. The explanation of this is different for different regions. In the Antarctic Regions the ice already covers all land south of latitude 60°, and it could therefore only increase in thickness but not in extent. Between latitudes 60° and 40° S. there is hardly any extensive land except southern Patagonia, which as a matter of fact was largely ice-covered. As the work of the Swedish expeditions in Tierra del Fuego, South Georgia, and West Antarctica has shown, the increase of ice was exceedingly large around the South Atlantic, so that during the Ice Age the ice masses there and around the North Atlantic may have been of the same order of magnitude if the extent and position of the land in relation to the poles is taken into consideration.

In contrast to this, it is remarkable that around the northern part of the Pacific the ice nowhere extended beyond the mountain regions, although it had essentially greater extent than at present. In Japan, which to be sure lies rather far south, no certain evidence of an Ice Age has been determined, although indications of glaciers in the high mountains are believed to have been found. In temperate and warm regions glaciation is not to be expected except in the mountains.

The increase of ice consequently was greatest around the southern and mainly around the northern part of the Atlantic. The observed conditions are such that it may be assumed that the amount of temperature decrease was about the same and was simultaneous all over the globe. In the areas mentioned, however, there may have been other particularly favorable conditions for ice formation.

Changes in the Extent of the Ice in Different Regions: Ice Types and Their Relation to Climate

Thus in the discussion of the main problem of the causes of the Ice Age we can limit ourselves to the best-known area, the North Atlantic, and especially its European part. Theoretically speaking, a heavier glaciation in an area can be produced by a sinking of temperature, especially the summer temperature, by increase of precipitation, or by a combination of both these factors. It is probably out of the question that a glaciation could arise in northwestern Europe simply by an increase of precipitation.[4] But the problem should be

[3] With these facts before him the writer has difficulty in believing that the Ice Age in *these* regions can be explained by a sinking of the mean annual temperature by 5° to 6° or perhaps 3° to 4°. The cold caused by the ice itself certainly is to be taken into account, and in Greenland inland ice is to be found in the *vicinity* of areas with considerably higher temperatures than those just given. But the ice there is stationary or receding, and the first expansion of an ice mass surely requires both low temperature and other especially favorable conditions.

[4] As regards the Antarctic Continent von Drygalski assumes that an increase of precipitation can account for the former greater extent of the ice sheet.

investigated whether glaciation could be produced by a more distinctly maritime climate, with colder summers and milder winters but with the mean annual temperature unchanged. The problem is best answered by a comparison. In the center of the sub-Antarctic zone of the Indian Ocean lies Kerguelen Island with a mean annual temperature of +3.5° at sea level, about the same as northern Norway (Bodö +3.9°, Tromsö +2.4°). The difference between summer and winter is very small: February is +7.0°, July +0.4° (Tromsö in July +11.4°, in February −3.9°). No more maritime climate than is indicated by these conditions is known on the globe.[5] Precipitation at the German station on Kerguelen in 1902–1903 was, to be sure, only 852 millimeters, but this is high in comparison with northern Scandinavia, especially for a station away from the outer coast, on the lee side of the island, namely east of the highest mountain range. On the western slope the rainfall is usually much greater. The altitude of the western mountain range is 800–1800 meters. It appears entirely out of the question that, with the existing mean annual temperature, conditions as favorable for ice formation can ever have existed in northern Scandinavia as they now do in Kerguelen, and yet this island carries glaciers only in its high western part. The glaciation of Scandinavia could not have arisen in this way.

A comparison of the climate in the northernmost part of Norway with that of the warmest of all areas that are at present covered by inland ice, namely southern Greenland, might lead to a different conclusion. The difference in temperature is on the whole not great, but the temperature is nevertheless lower in Greenland, whether one compares the outermost skerries at Cape Farewell with those at North Cape (Sagdlit, mean annual temperature +0.1°; Fruholmen, +2.0°) or localities lying somewhat farther in (Ivigtut +0.5°; Tromsö +2.4°). Neither is the difference in precipitation so great (Ivigtut, 1145 mm.; Tromsö, about 1070 mm.) as to explain the existing enormous differences in glaciation. But, on the other hand, any comparison that only takes these figures into account must be misleading. The southern end of a narrow polar land whose glaciers stand in uninterrupted connection with inland ice formed under much greater cold and where the precipitation is large on both sides, cannot be thus compared with the northern end of a continental land mass whose summer on the inner side of the mountain range is warm and dry. The formation of inland ice in Scandinavia requires a climate in its northern parts considerably more favorable for ice formation than the coastal area of southern Greenland now is, though this area, to be sure, is cold and moist.[6]

[5] In the Faeroes the annual range is 7.7°, consequently a little larger.

[6] To be sure the question would be different if we could assume that there existed at that time a land connection to the north and that the ice had its nucleus and origin not in Scandinavia but in this land.

The Causes of the Decrease in Temperature

An increase of the precipitation due to a lowering of the temperature may have contributed to the formation of ice, but the beginning of the Ice Age, that is the first major expansion of the ice, must be largely due to a lowering of the mean temperature of the year or especially of the summer. In itself this supposition is not improbable, as it is a well-known fact that climatic changes have frequently taken place in the history of the earth and that the Tertiary in particular was warmer than the present time. The temperature lowering may have been local. Certain areas, that is, may have grown colder while others became correspondingly warmer, or the lowering may have been produced by upheavals of certain areas and thus have been in reality only ostensible. Or a temperature lowering may have been general, affecting the whole globe. In the latter case also the temperature lowering may theoretically have been only apparent if the level of the sea be supposed to have been lowered all over the globe.

If only the large Pleistocene ice sheets on both sides of the North Atlantic are taken into account an explanation belonging to the first group would seem most probable. Considerable upheaval of land in a very late period is evident among other reasons from the highly upheaved Tertiary strata on the coasts of Greenland. The high mountain plateaus also attest this, if it can be assumed that at least in part these have been formed at sea level. Several students of the question have assumed that this upheaval was so great that the glaciation was the result. As evidence of such upheaval certain deposits on the bottom of the North Atlantic are cited; also the fiords, which by many are considered to be old, land-developed valleys that have sunk below the level of the ocean. If these views are correct, the land must have lain at least 1000 meters higher than now. Personally I do not think that the fiords furnish evidence of any substantially higher position of the land than now. But even if they did, hardly any conclusions regarding the causes of the Ice Age could be drawn from this fact, for they would indicate a long-continued high position in preglacial time, *without* greater ice masses. Aside from this, it may with good reason be doubted that even in this case the thick inland ice could have arisen. To be sure, considerable lowering of the temperature could have been brought about in the whole area if the inflow of the warm water of the Gulf Stream into the Arctic Basin had been prevented by upheavals. But fairly analogous conditions are to be found even now around the northern part of the Pacific, with a mountain chain that is higher than the Scandinavian mountain chain would be even if it were upheaved an additional 1000 meters. The winter temperature in Alaska is therefore much lower than in Scandinavia, but inland ice never existed in this area.

It is not to be denied that a large upheaval would greatly aid or, under favorable circumstances, even cause a glaciation. And it is evident that the existence of a highland, the higher the better, also indirectly favors the formation of a large ice mass, both because the precipitation under otherwise similar conditions always is greater in a highland and perhaps also for other reasons, if, as J. W. Sandström holds, a cool highland causes a lively exchange of air with the surrounding regions and thus results in increased condensation.[7] It is on the whole rather difficult to realize how a lowland ice of continental dimensions is formed without connection with a highland or a previously existing inland ice sheet. Known conditions in the Polar Regions, with the exception of the shelf ice, do not give a clue. However, hardly more than one such glacier is known in the earth's history, namely the previously mentioned Keewatin Glacier which had its center on the large Archean plain, the present tundra, west of Hudson Bay. This is the more difficult to explain as the purely polar Arctic Archipelago, farther to the north, seems to a large extent never to have been covered by ice. As long as no evidence has been presented indicating that the region during the Quaternary lay considerably higher than at the present time, it is, according to the writer's opinion, most probable that the Keewatin ice had its origin in the mountain plateau of Labrador and possibly only later was separated from the Labrador ice sheet.

Extensive glaciation, however, limited to certain parts of the globe, can be explained in other ways than by local uplift of the land. Among these are the hypotheses that assume alternating glaciation in the northern and the southern hemisphere as a result of changes in the eccentricity of the earth's orbit and attempt to explain the temporary displacements of the whole Polar Region by changes in the position of the earth's axis. The first view may not have many adherents at present. It is contradicted both by what we know of the distribution of glaciation in the equatorial regions and by the repeated relatively rapid climatic changes during Quaternary time. The large existing Antarctic ice cap surely is not due to less favorable insolation than in the Arctic but to the existence of the high-polar continent with its cold center. The view that the increased glaciation was due to migrations of the poles is disproved by the fact that both areas where the glaciation was heaviest are situated on the same side of the earth and in the same zone.[8]

In this connection a view held by many investigators deserves to

[7] W. Ramsay explains glaciation by the fact that, after a period of great upheaval, especially in the polar zones, the air circulation and radiation become greater, so that snow and ice masses accumulate and in themselves cause more favorable conditions for their continued growth. That locally this was a contributory cause in the formation of an ice cover seems quite probable; that it quite generally can explain the Ice Age seems to be, however, very doubtful.

[8] The improbability of this hypothesis is also pointed out by Fredrik Enquist, who has shown that the anti-trades during the Ice Age prevailed in the same area and blew in the same direction as now.

be mentioned, namely that the climate in the Antarctic is already so cold now that a further lowering of the temperature probably would cause a *decrease* in precipitation and thus also in glaciation. The late Eduard Brückner has developed the interesting view that during a milder climate the so-called upper snow line, i. e. the upper limit of heavy precipitation, ought to rise and thus cause an increase of snow accumulation. If the glaciation in the south could be explained in this way by a rise of temperature and that in the north in a normal way by a fall of temperature, the hypothesis of migrating poles would receive strong support. Theoretically this seems fairly reasonable, but practically such a theory is hardly feasible. In the first place, it is impossible to explain the increased glaciation at the southern point of South America or in South Georgia by a rise of temperature; and then, too, the distribution of the ice in northern West Antarctica is decidedly opposed to such a view.[9]

For a single area, even of such dimensions as northern Europe, the great expansion of the ice can probably be explained by local changes; but the general distribution of the phenomenon over nearly all parts of the earth shows that in itself the decrease in temperature must have had a general cause. Naturally this does not exclude the coöperation of local causes at many places to make the increase of the ice greater or less than normally.

Such a decrease in temperature may have been due to several causes, and it is not yet possible to decide which is the true one, even though several conditions now suggest that changes in the solar heat were an important factor. If Gerard De Geer's highly suggestive studies on varve clays and the time correspondence in the melting of the ice over large parts of the globe, north and south, prove to be correct, strong evidence would be adduced that at least the disappearance of the ice had such a cause. But other possibilities, such as changes in the composition of the air, etc., can by no means be disregarded.

Ice-Border Climates

All that is known about the properties and distribution of the ice in the present and during the Ice Age consequently indicates that the Ice Age was introduced by a real, probably considerable fall of temperature affecting the whole globe at the same time, even if not to the same extent everywhere. On the other hand, there are various reasons, especially of a phytogeographical nature, for the assumption that the climate *at times*, both during the Ice Age itself and later,

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[9] It is, to be sure, true that in so cold a climate further cooling ought not directly to increase the snowfall; but, as H. H. Hildebrandsson has pointed out, such an increase can indirectly be explained by the fact that during a colder period the sea would have been more ice-covered, so that violent storms may have been less frequent and the precipitated hoarfrost may more easily have accumulated and remained. [On Simpson's view concerning the mode of nourishment see, above, Chapter II, footnote 6.—Transl. Note.]

was rather mild. All that we can learn in the Polar Regions of today regarding the climate at the ice border is of great interest in this connection. It has already been mentioned that the climate here can be very different in different areas. The fact that in moist regions with cold summers and mild winters, such as western Patagonia and New Zealand, glaciers may extend down into forests of the subtropical type is of subordinate interest in this connection. Such glaciers are but small. An inland ice may dry out and cool its surroundings too much to permit such a climate at the ice border. On the other hand, it is not impossible that such a climatic type, during the epoch of ice recession, existed at the foot of the Alps. The inland-ice area which now most resembles those mountains during the Glacial Period is southern Greenland; but the little that is known about the climate at the very ice border seems to indicate that it is arid and that the contrast between summer and winter is fairly great. The well-known southern Greenland climate is a coastal climate, independent of the land ice. In the Antarctic the climate at the ice border in both summer and winter is enormously colder because of the cold winds that sweep down from the ice as a result of the great contrast in temperature between land and sea. Similar conditions at times may have prevailed on the Atlantic coast, for instance in the North Sea area. For the immense areas where the inland ice ended on land, comparison with the only well-known area in which the same condition now prevails, i. e. the Holsteinsborg District, is of particular interest. The summer there is dry and comparatively warm probably because the region lies within the barometric high-pressure area produced by the ice, with the consequent high degree of insolation in the clear dry air. On the border of the European ice sheet easterly winds furthermore may have prevailed, increasing the drought and the summer heat. Both in Europe and in America traces of widely distributed typical steppes have been found dating from that time, and most investigators assume that a substantial part of the loess deposits were formed then. On the other hand, it should be kept in mind that the drought in such an area does not completely dominate, as the melting of the ice must give rise to a rich irrigation in the valleys, whose vegetation during the steppe period may have been quite luxuriant.[10]

There is surely every reason to assume that the climate at different parts of the ice border and during different stages of the Ice Age presented very great differences, much greater than are to be found at the present time in the various areas bordering the ice sheets. On the other hand, the climate may on the whole have been very mild during the time of the waning of the ice, as it otherwise could hardly have been

[10] In Sweden also several observations have been made indicating that the climate during the stage of the last ice recession was arid in the vicinity of the ice border and that the landscape was steppelike in character.

able to overcome the cooling effect of the ice. This mild climate also was of importance for the fauna and flora, and it enabled the melting of the ice to proceed as rapidly as Gerard De Geer's studies have shown.

The Interglacial Periods

Regarding the great and important problem of the interglacial periods—their occurrence, climate, and duration—polar studies give no information. Opinions regarding these periods differ greatly, but it seems to be generally held that at least one or two of them were of great duration and had a climate which perhaps was milder than that now prevailing, so that the extent of the ice was not greater than now. Some deposits recently studied from northern Sweden possibly point in this direction. However, caution should be exercised. As we have seen, it is not particularly difficult to explain a uniform Ice Age, but strong and convincing evidence is necessary for such great and rapid climatic changes during the brief Quaternary as would be necessary for repeated independent glacial epochs. Especially is this true when we consider that the enormous ice sheets that covered the continents each time would have been formed in about the same area and would have attained about the same size. The expansion of the ice sheet becomes incomparably more easy to explain if it can be regarded as a practically uniform feature and if it can be assumed that even during the warmest epochs sufficiently large masses of ice remained to cause a new expansion of the ice period at a small lowering of the temperature.

How does this agree with the known facts? We may be sure that the comparatively small glaciers of the Alps as well as the lowland ice in Germany oscillated repeatedly and that the climate during certain epochs was mild. This latter is obvious, as the ice otherwise could not have withdrawn, and it does not prove that the ice border lay far away. If it is assumed that the large Central European ice had the character of shelf ice and had insignificant thickness, fairly large changes in the position of the ice border can be explained with comparative ease. The Swedish interglacial deposits just referred to may be more difficult to understand, but even these observations could probably be explained by greater oscillations having taken place during the time of waning, if it is admitted that the climate then was mild. From the intense weathering of certain old Quaternary deposits, not too far-reaching conclusions regarding the length of the Ice Age should be drawn, as observations in the marginal belt of the Greenland ice show that the weathering under these natural conditions may proceed very rapidly.

Conclusion

Thus the explanation of the appearance and conditions of the Ice Age still presents great difficulties, but comparison with the Polar

Regions of today, which has enabled us to realize the existence of such a period, promises further important clues and results. It is of particular importance to realize that, just as different parts of the now ice-covered Polar Regions present very different natural conditions, so general conclusions cannot be drawn from observations of the climate and vegetation in a certain area and during a certain epoch of the Ice Age. It should also be pointed out that the appearance of such high-polar ice forms as inland ice and shelf ice in the lowlands of Europe, for instance, can hardly be explained by such a small actual fall of temperature as that by which it has been attempted to explain the lowering of the snow line in the Alps during the Ice Age.

CHAPTER IV

SOILS AND LANDFORMS

Polar Soil Types

While it is especially the climate and the ice that give polar nature its aspect, there are evidently several other features also, more or less dependent upon these, that contribute to its character. A few of

Fig. 10—Strongly weathered ridges of gneiss at the border of the inland ice. Holsteinsborg, western Greenland. (Photograph by the author.)

them should be dealt with here, viz. the nature of the soil, the landforms, and the flora and fauna.

The surface of the ground in the Polar Regions does not in itself present anything especially remarkable. However, it is to a large extent broken up by frost action into jagged pieces of rock, a feature otherwise met only in high mountains. In the Archean regions of Greenland and Spitsbergen extensive lowland areas may form veritable plains of these rock blocks. I was rather surprised to find in the gneiss regions of western Greenland evidences of especially intensive weathering up to the very border of the inland ice (Fig. 10). This

must have operated since the Ice Age, and the fact that in Sweden similar features so seldom occur seems to show that a polar climate prevailed there for only a short time after the waning of the inland ice, if it did at all.

It is of course natural to expect that the ground in the Polar Regions to a large extent would be formed by such frost action and by the direct action of the ice, but otherwise it does not materially differ in its composition from that in more southern regions, where, as for instance in Sweden, Arctic conditions prevailed earlier. One unexpected feature may be mentioned, namely the occurrence in certain polar areas of formations that normally belong to arid steppe regions. Peculiar forms of weathering have been described from the Antarctic and have been studied by the present writer and by others in western Greenland. In the warm and arid region inland from Holsteinsborg, already described, the writer found at the ice border a fairly thick layer of fine-grained soil which owes its origin to gradual wind deposition of the finest glacier mud on these grassy plateaus.[1] It is of the greatest interest to compare this formation with genuine loesses in more southerly regions, whose origin is both interesting and debated. It can easily be shown that in appearance and consistency they are rather different, and it is not probable that loess has everywhere been formed in exactly this way. But many investigators, as is well known, have for a long time been inclined to attribute it partly to a glacial origin, and the differences may in part be explained by certain minor variations in the formations, especially by the fact that Greenland soil is derived from a chemically almost unweathered Archean rock, while, for instance, the loess of central Europe, which was deposited outside the outermost ice border, may be derived from strongly weathered rocks, mostly younger and looser, with a fairly high percentage of lime.

Solifluction and Polygonal Soils

The remaining ground in the Polar Regions presents a rather striking and interesting feature which is elsewhere found only in higher mountain regions, and even there not often, namely the so-called "striped ground" (*strukturboden*). During my participation in the Amdrup expedition in 1900 I noticed at several places on the mountain slopes on the eastern coast of Greenland this feature, which had not then been described in detail, namely a peculiar arrangement of the soil in narrow, more or less regular, rows or stripes of coarser and finer gravel and sand elongated in the direction of the slope. By some force or other the soil had apparently been assorted according to its coarseness and at the same time or later had become arranged in rows extended in the direction of gravity. At about the same time J. G.

[1] Similar large areas of Quaternary eolian deposits, corresponding to loess, have been described from Iceland (*móhella*).

Andersson under the name of "solifluction" described a feature which seems to have wide distribution in the Polar Regions and perhaps even exerts an important influence on the development of landforms. He found, namely, that at certain places the ground, saturated by melt-water during a large part of the summer, is half afloat and on slopes then undergoes a slow downward movement. During this

FIG. 11—Striped soil, a form of *strukturboden:* gravel and sand arranged in rows on a gentle slope. Snow Hill, West Antarctica. Note the absence of practically all vegetation. (Photograph from Swedish Antarctic Expedition.)

process a certain striped arrangement of the soil with alternating coarser and finer material or else an arrangement in small irregular terraces limited by low walls is not seldom brought about. Both these formations are undoubtedly rather closely related, although solifluction, which is not a distinctively polar feature, in general geographical importance greatly surpasses the peculiar and little-understood *strukturboden*. This latter formation has lately been studied by the present writer both in the Antarctic and in some higher mountain areas and has been a subject of recent interest to a large number of investigators. On level ground the striped soil of the slopes is represented by an arrangement in more or less irregular hexagonal netlike rows where the interspaces consist of finer sand and the central parts of each mesh consist of gravel and larger stones frequently standing on edge. The feature is strictly confined to regions with a polar climate and so far as known to places with almost continuously frozen

FIG. 12

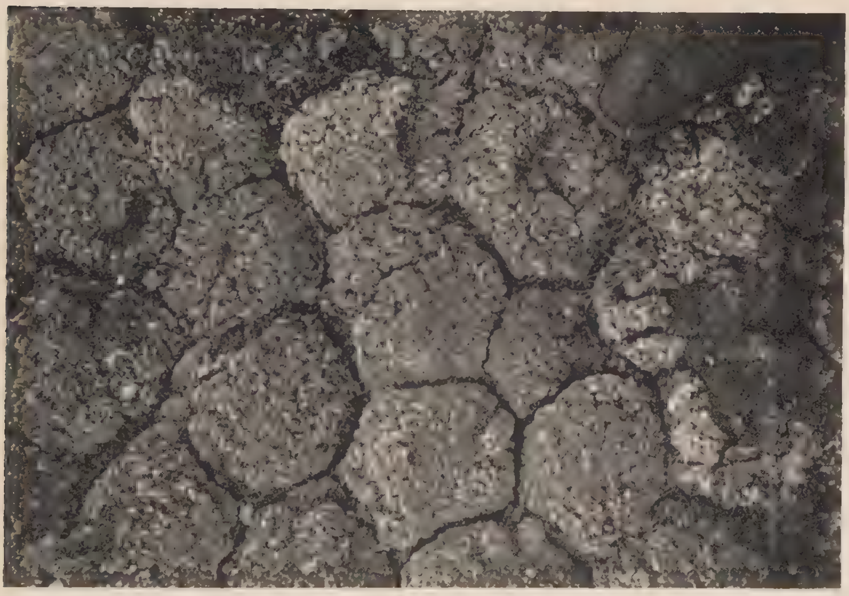

FIG. 13

FIG. 12—A form of *strukturboden:* polygons of fine clay with practically no vegetation, separated by netlike perimeters with relatively more abundant plant life. Where the polygons normally consist of gravel they are bare and the vegetation is concentrated on the outer, ring-shaped part of the interspaces. (Photograph by H. Resvoll Holmsen, Isachsen expedition to NW. Spitsbergen, from *Rés. des Campagnes Sci. Albert I, Prince de Monaco, No. 44,* Monaco, 1913, Pl. 3, Fig. 1.)

FIG. 13—Half-open hexagonal cracks in *strukturboden,* or polygonal soil. Sassen Valley, Ice Fiord, Spitsbergen. Note the toe of a shoe as scale. (Photograph from Duke de la Victoria.)

ground.[2] It is strange to see how in the Norwegian mountains *strukturboden* completely dominates the whole Gjuvvas plateau at Galdhöpiggen, at an altitude of 1900 meters, while it is completely lacking on the adjacent Valdresflyen at 1300–1400 meters, though this is apparently formed of the same kind of soil. My first impression was that the striped arrangement could be explained by water currents in the soil together with a sliding motion of the material on the subjacent frozen layer and that also the hexagonal meshes could be explained by a slow water circulation in the same direction caused by differences of temperature. The pronounced assortment of the material, however, can hardly be explained in this way, whereas it is evident that the significance of the frozen substratum lies in the fact that it prevents the water from sinking. Bertil Högbom's calling attention to the importance of regelation, i.e. a repeated freezing and thawing, for the reassortment of the original unassorted mass of coarser and finer morainic and weathered soil, was therefore an important step forward. Later, however, John Frödin pointed out in the mountain regions of Lapland that regelation there during the summer months hardly takes place to a greater extent than in many temperate regions, and a fully satisfactory explanation may not yet have been reached by Högbom's supposition. But, on the other hand, it is not certain that alternations between freezing and thawing need be specially frequent, provided other conditions are favorable and the time sufficiently long. The late Icelandic scientist Thorvaldur Thoroddsen held that each section of the net is originally bounded by fine fissures that are filled by water which freezes at night and, together with the frozen substratum, divides the soil into a number of separate cells. In each of them the water rises by evaporation and capillary action as the ground is warmed by day; by night it freezes again and thus lifts the central parts of the cells. As a joint result of this warming and freezing the finer clay material is gradually brought towards the center of the cells while the gravel, pebbles, and cobbles are pressed towards the margin. F. Klute assumes that these more or less circular fissures open when the ground contracts in freezing and close again when it thaws, during which process the coarser material is very gradually pushed toward the border of each polygon. At any rate it is certain that this phenomenon arises in regions with a polar climate through the combined action of long continued water saturation above a substratum of frozen ground, and of frost, evaporation, and sliding.[3]

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[2] Forms of *strukturboden*, according to reports, occur occasionally even in regions with less pronounced polar climate, for instance in Iceland and in the forest region of Lapland. It is also possible that it may occur under otherwise favorable conditions, even if the substratum thaws out entirely during part of the summer; but, on the other hand, it is also possible that it is a relict here from an earlier colder period.

[3] Thoroddsen explains according to the same principle the formation of compact and steep mounds, often a meter high and two meters or more in diameter, frequently met with in Iceland on plateaus up to 1000 meters in altitude but never observed by the writer in the Polar Regions proper.

Characteristic Landforms

The first fact that becomes apparent, as we attempt to describe the most important landforms of some of the polar countries not covered by ice, is that they all consist of higher or lower mountain areas, whereas typical lowlands of larger extent are practically absent. As this cannot well be an accident, the explanation may be that what would be lowland is covered by the sea, which consequently in the Polar Regions may stand relatively higher than in other parts of the globe. That this is really the case is evident from the fact that the shallow continental shelf which surrounds so much of the land of the globe at a depth of about 200 meters—off the coast of Europe, for instance, the bottom of the North Sea belongs to this plateau—at least around the Antarctic Continent lies from 200 to 300 meters deeper than usual; only if the land rose this amount would normal conditions prevail.[4] The cause of this condition is usually thought to be that the ice by its weight has pressed down the crust of the earth to this extent.

It is well known also that Scandinavia during the Ice Age stood at a lower level than now; but these observations refer essentially to the final stage of the Glacial Period and cannot be applied to conditions at the climax of the period. On the other hand, it has been held by many that the glaciation in some way was caused or substantially increased by the fact that the land then lay higher than at present. Our observations in the Antarctic, the most heavily glaciated area on earth, are, however, of great interest as showing that this can hardly have been the case there; to be sure it is not impossible that even this region once lay higher,[5] but in any case the later extensive sinking of the land did not prevent all land north of the Antarctic Circle from being covered with ice.

In regard to landforms a great number of ordinary morphological types may be distinguished in the Polar Regions: real mountain chains, plateau areas of sedimentary as well as volcanic origin, and elevated and deeply dissected mountain masses. In Greenland, which is not only the most heavily ice-covered land in the Arctic but also one of the regions where the largest ice-free areas occur, the outer coast in great part is dominated by a rugged topography, while the strip back of it consists of lower hilly land with elevations a few hundred meters high. An especially good example of this type of landscape is to be found in the Holsteinsborg and Egedesminde districts, where it extends all the way to the ice front. That is, however, an exception. As a rule one finds in the inner parts of the large

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[4] The submarine plateau between Norway and Spitsbergen for a large extent has a depth of 200 to 400 meters; it is shallowest toward the north.

[5] This is not very likely, however, as we have found fossiliferous deposits of earlier glacial ages, which occur probably *in situ*, at an altitude of several hundred meters above present sea level.

fiords, both of the east coast and of the west coast, deeply dissected coastal mountains, and these unite to form large massifs truncated by level, sometimes ice-covered, plateaus. Although the question cannot be fully decided it is my belief that the land under the Greenland ice cap—at least large parts of it—consists of such extensive and on the whole fairly level highlands, which would explain the smooth surface of the ice sheet and its freedom from nunataks. In order to understand this physiographic type, surely one of the most interesting in the Polar Regions although it is largely covered by ice, it is necessary to compare it with similar landforms in other parts of the earth. Best known are the mountain plateaus (*fjeldvidder*) of central and southern Norway, but similar upland plains seem to exist in Labrador, and they are also found, though at a lower level, in northwestern Spitsbergen and northern Norway. They may also exist in the Antarctic, though it is difficult to prove that they occur there. On the other hand they seem to be lacking in regions where there has been no ice covering. It is therefore probable that these mountain plateaus stand in some relation to the ice of the glacial periods. Nevertheless I consider it more likely that they are old denudational surfaces or raised peneplains that have been preserved by the protecting ice cover rather than that they are the product of frost weathering and ice erosion. In an upland region, therefore, the work of ice would seem to express itself in the greater deepening of the major valleys—resulting in the development of fiords—and the preservation by the ice cover of the flat surfaces, both those at lower and at higher levels, but more especially the latter.

The Strand Flat

Finally a few words should be said of a feature also frequently discussed in recent years, namely the low rocky plain on the Norwegian coast, the strand flat (Fig. 14) to which Reusch first called our attention. It is a narrow coastal belt of low land and skerries which on the landward side abuts quite abruptly on the interior high land. It is a very characteristic feature of the Norwegian coast, and it is important from the standpoint of human geography because in this region, where the high mountains otherwise rise steeply from the sea, it furnishes the foundation on which fishing villages and other habitations are situated. At first the strand flat was thought to be formed by the abrasive action of the waves of the sea, and this view no doubt has a good deal in its favor and may still be the most commonly accepted. Several morphological reasons, however, speak against it, for instance the slight slope of the surface even in a width which frequently amounts to 10 to 20 kilometers if the skerry belt is included. An additional objection and the most important, however, is that nobody has yet been able to give any reason why wave action should have been so

potent just in this region. Rather, it seems as if this formation also is geographically limited to the areas that have been or are ice covered; or at any rate it is best developed in such regions. Therefore Nansen, who believes that he has been able to establish the occurrence of similar features in Greenland and possibly also in Labrador and Spitsbergen, has suggested that the origin of the strand flat is in some

FIG. 14—Well-developed strand flat in the shape of low skerries abutting on the interior high land. Coast south of Holsteinsborg in western Greenland. (Photograph by the author.)

way connected with the Ice Age. He conceives it to have been produced by the combined action of waves, drift ice, and very strong frost weathering in a cold climate. Lately I myself have had opportunity to study an especially fine strand flat on the west coast of Greenland, and in describing it I have attempted to explain its origin by assuming that the edge of a shelf ice or ice foot of Antarctic type, which had long been attached to the coast while extreme-polar climatic conditions prevailed, had gradually eaten itself backward into the land as a result of the intensive frost weathering, much in the same manner that the ice in cirques is assumed gradually to work backward and erode them out. To be sure this explanation, too, meets with difficulties, one of which is that strand flats of this type should occur more frequently under such conditions. Also, it now almost seems as if, like the high mountain plateaus, they occur only in old mountain regions. However, this may be a coincidence, because shelf ice of the

type we speak of here surely never had any wide distribution. Again, according to this explanation such strand flats should occur in the Antarctic Regions. The fact that hitherto none have been described from there may, however, be due to several reasons, either that they are still covered by ice or that they are submerged beneath the sea, or also in certain cases simply because they have not been observed. Further studies in the Antarctic are obviously necessary.

CHAPTER V

VEGETATION AND ANIMAL LIFE

The Character of Polar Vegetation and Its Zonal Distribution

In this remarkable realm of nature where the summer lacks warmth and the long winter is not only cold but also part of the time entirely dark and where the greater part of the ground is covered with ice and snow both in summer and in winter, a flora and a fauna are to be found which for several reasons are of particular interest. These cannot, of course, be treated at great length here but merely so far as to show how the plants and animals have adapted themselves to the polar nature.

The first impression received in the Polar Regions is that plants and animals, both as regards number of species and of individuals and as regards development, represent dwarfed forms of species met in climatically more favored regions. This is, however, hardly correct. The number of species, to be sure, is small; but the species that occur are as highly developed as their relatives living farther from the pole; only they are very intimately adapted to their environment. The features in their appearance, especially those in the vegetation, that suggest a dwarfing are, as a rule, just those that depend on such an adaptation. This holds true especially for that characteristic of polar nature which, along with the predominance of ice, first strikes us, viz. that trees and high bushes are entirely absent, while instead representatives of genera that with us are tall trees here often creep along the ground. Therefore the polar tree line forms the outermost natural limit of the Polar Regions or, if we so prefer, of the outer belt of those regions. Inside this limit the polar lands with respect to vegetation may be divided into three or four large ring-shaped areas which closely correspond to changes in the summer temperature. That the correspondence cannot be complete is due to the fact that several other conditions also considerably influence the luxuriance of the vegetation. Thus the low air temperature is greatly compensated by the strong insolation, which, during sunshine that may last here all day and night, permits the temperature of the ground and of the air about the plants to rise considerably.[1] On the other hand, besides the cold the plants have two mighty enemies: first, drought, accentuated by the slight precipitation and by the freezing of the ground at

[1] According to Gunnar Andersson the temperature in plant clumps can be as much as 10° C. higher than in the surrounding air.

Fig. 15

Fig. 16

Fig. 15—Bush vegetation of dwarf birch, willow, alder, etc., around an old Norse ruin in the interior part of Godthaab Fiord, western Greenland. (Photograph by the author.)

Fig. 16—Ice-free mountain valley, with exceptionally rich moss vegetation, on Petermann Island in the northernmost, least cold part of the West Antarctic area. An example of polar desert tundra. (Photograph from Jules Cardot: Mousses, Deuxième Exped. Antarctique Française: Sci. Nat., Doc. Sci., Paris, 1913, Pl. 1, Fig. 1.)

an insignificant depth, and, secondly, wind, which in itself is unfavorable and increases the evaporation and desiccation especially of all tall plants. Therefore in the Polar Regions especially luxuriant vege-

tation is to be found only in moist valleys protected against the wind—real oases, as compared with the surrounding desolate areas.

Let us now return to the three great phytogeographical belts of the polar world, which, however, with regard to their climate and general nature, will be more closely discussed in the following chapter.[2] The first among these comprises approximately the areas situated between the mean July isotherms of $+10°$ and about $+5°$ C. and can more simply be classified as the polar tundra. Here belong primarily the greater part of the northernmost continental areas of Asia and America and the southern portion of the American Arctic Archipelago—thus the very regions which on account of the higher summer temperature as a rule lack a cover of perpetual ice. Certain other regions, also, as, for instance, the coast areas in the southern half of Greenland are, in spite of the proximity of the inland ice, climatically to be counted here. The vegetation in this whole area is characterized by a closed meadow or heath type, a polar steppe which in Siberia bears the name of tundra; here the valleys and, especially in the interior of the continents, vast plains are covered by a uniform flora consisting chiefly of creeping bushy plants—among which *Cassiope* and *Empetrum* are in places the most important—and of sedges, mosses, and lichens. In spots the vegetation becomes still more sparse. In the southern parts, in protected places of the type mentioned, however, it may become relatively luxuriant (Figs. 15 and 20), with high-stemmed bushes and, in southernmost Greenland, with real birch forest even if it is low and distorted. Going northward to Upernivik, at the innermost limit of the belt, these bushes of dwarfed birch and willow still reach a height of about a meter with stems five centimeters thick, and at the same time flourishing herbaceous vegetation frequently occurs. Because this bush vegetation is especially noticeable to the eye and therefore stands out against other parts of the belt, it seems fitting to classify it as a distinct, fourth, phytogeographical transition region.

The polar belt proper, the zone with which we are particularly occupied in this work, begins where the mean temperature during the warmest months of the year sinks below 5° or perhaps 4° C. Even if some areas on the Arctic Sea margin of the continents that are largely free from ice in summer must also be included here, *ice* remains the characteristic feature in this belt, and it is here, partly as a result of the lesser occurrence of low land, that the various types of ice described in Chapter II are to be found. Even inland ice in Greenland belongs to this belt and reaches, as we have seen, still farther south; only shelf ice does not occur in this zone. The characteristic feature of the vegetation is that the higher plants as a rule are only found in knolls or mats, separated by larger or smaller areas that are entirely bare and sterile. The peculiar types of solifluction, *zellenboden* and

[2] See also the maps, Figs. 23 and 24.

striped ground, play a great rôle and give rise to bare spots and strips (see Figs. 12 and 13, both from Spitsbergen). The colder the summer, the sparser the vegetation. While southern Greenland has more than 300 species of phanerogams, northwestern Greenland has only about 130, Spitsbergen 129, and Franz Josef Land only 23 species. In the whole American Arctic Archipelago only a little more than 200 vascular plants are known. But here, also, in the most desolate ice-free regions of the Arctic, the vegetation imparts to nature a life and variety that are lacking in the warm-climate deserts; and among the few flowering plants there are several of the most beautiful and typical forms of the polar world.

There is, however, among the polar lands another region which in naked sterility is far more extreme than the belt just discussed and which therefore must be set off as a third division, namely the enormous land areas in which the mean temperature even in the middle of the summer lies below the freezing point and in which snow falls even in that season. It can readily be understood that these areas are largely covered by ice, partly by inland ice, partly also on the coasts by shelf ice, the most distinctly extreme-polar form of ice. It is therefore only on some narrow coastal rims and on scattered nunataks that, within this region, scanty vegetation is to be found. In the Arctic zone there is hardly any ice-free land except some few nunataks that can be included in this category; but this third type, the polar desert, entirely dominates the Antarctic Continent and thus in reality affects the greater part of all polar lands. Vegetation is extremely scanty in this area (Fig. 16). The only two Antarctic flowering plants thus far known—a dicotyl of the genus *Colobanthus* and a grass—are found exclusively on a few well-protected localities in the very outermost belt, where the mean January (mid-summer) temperature really exceeds 0° C., plants which we had best assign not to this but to the preceding zone. Of Antarctic mosses 63 species are known, that is to say about as many as Peary found in a restricted area in latitude 82° N., but here in the south they almost all occur outside the Antarctic Circle. Only six species have been found as far south as South Victoria Land. In addition a number of lichens are to be found, but the greater part of the ground is devoid of all vegetation (see also Fig. 11). There remains the question how any vegetation can grow under such conditions. That this is possible is chiefly due to the strong insolation which during the sunny summer days, in spite of the fact that the air temperature remains below 0° C., can raise the temperature in the uppermost layers of the soil to +30° C. At the Swedish Antarctic station in the summer time a fairly rich bacterial flora was found in these layers. In general, pathogenic bacteria especially are uncommon in the Polar Regions, and hence in the very coldest places human beings are not subject to colds.

To summarize, therefore: We distinguish four main zones of vegetation in the polar world (four as against the three previously mentioned, because of raising to coördinate rank the southerly belt (a) of the first zone). This classification is based on the localities where plant life is best developed; sterile spots and areas can be found in all regions. Farthest from the pole, in not too severely exposed places, we find (a) a transition zone with *bushes* of willow (*Salix*) and, more exceptionally, of dwarf birch, alder, and mountain ash. Fine examples of this type are seen in southwestern Greenland and also on the southern islands of the American Arctic Archipelago, where, in particular, Stefansson described the luxuriance of nature. Only the next zone, however, is truly polar: (b) the *grass tundra*, interspersed with mosses and lichens and on the whole still having a continuous plant cover. This type prevails in the northern part of the Arctic Archipelago and is also found in the valleys of Spitsbergen, in the central west coast of Greenland, etc. On all the ice-free lands in the inner Arctic and along some specially favored coast stretches in the Antarctic—mostly along the northern channels of the Graham Land region—this zone gradually passes over into another which we may designate (c) the *desert tundra*, consisting of individuals of cushion and mat types of higher plants growing scattered and separated by areas that are either bare or overgrown with scanty lichens. Only where moisture is present does the vegetation become somewhat more abundant and arrange itself at times in regular figures (so-called pseudo-*strukturboden*). The last zone is (d) the true *polar desert*, comprising the vast regions dominated by the inland ice and including some adjoining ice-free strips, which constitute almost all the exposed land in the Antarctic. Here immense areas are to the eye completely devoid of vegetation, and only here and there in favorable places is an extremely impoverished flora of moss and lichen to be found.

The Animal World

Of no less interest than the flora is the fauna that braves the darkness, cold, and storms of the Polar Regions. In the outermost belt with its relatively temperate summer climate this animal life is rather abundant, especially in areas that stand in direct land connection with the continents. These, however, will not be discussed here. In the inner Arctic Regions also several species of higher animals are to be found living on the locally luxuriant vegetation. Even in northern Greenland, which belongs to this zone, at least four plant-eating mammals are to be met with: namely two larger, the reindeer and the musk ox (Fig. 17), and two smaller, the polar hare and the lemming. It is hard to realize how these animals can endure the long, dark winter nights. Besides these, there are several predatory animals

FIG. 17—Arctic animal life: musk oxen on the tundra of Jameson Land, east coast of Greenland. The habitat of the musk ox consists of the Barren Grounds, the Arctic Archipelago except Baffin Island, and northern and eastern Greenland. (Photograph from Danish Greenland Expedition, 1900.)

and a number of lower forms, such as land birds, butterflies, beetles, etc. In the Antarctic zone, lacking vegetation, the animal life is entirely different. Here all higher land animals, both mammals and birds, are lacking. Of lower animals, besides some semi-microscopic acarids and podurans, only a wingless mosquito, found at a single protected locality, is known (cf. Fig. 18). The causes of this are evidently the sparsity of the vegetation, the cold climate, and the violent winds. It should be remarked that predatory animals are also entirely absent from the antarctic.

FIG. 18—Antarctic animal life: wingless mosquito (*Belgica antarctica*), the largest land animal on the Antarctic Continent, magnified seventeen times. (After the Belgian Antarctic Expedition.)

However, it should not be thought that on the whole the animal life or even the higher fauna is really poor even in this the most pronounced polar zone. In the sea, whose temperature to be sure also lies below 0° C. but where the winter cold and the storms cannot disturb the organisms, a particularly rich flora and fauna exist. These in their turn serve as food for a number of higher animals, largely water birds but also one meat-eating wading bird and, if we include the outer zone, six kinds of seals. Many

of these animals are found in enormous numbers. This is especially the case with the strange penguins (Fig. 19), the most characteristic inhabitants of the Antarctic region and a constant subject of lively interest to all expeditions in these regions. Such a type of bird, without ability to fly and rather awkward and defenseless on land, could hardly exist in a region where it is exposed to the attack of land animals.[3]

FIG. 19—A colony of penguins, the most characteristic representatives of the Antarctic fauna. (Photograph from the Swedish Antarctic Expedition.)

But it is of exceptional interest to see how these birds have succeeded in adapting themselves to the great climatic difficulties.

In the Antarctic waters the largest mammals of modern times, the whales, are also met in greater numbers than elsewhere on the globe, in greater numbers than anywhere else even before they were hunted by man. They appear during the summer in great herds at the ice border and sometimes in among the drift ice and even far from land. It was the whale fishing that, as early as the sixteenth century, first attracted attention to the Polar Regions and, for example in Spitsbergen, gave rise to the founding of whole cities. In later years whales have brought life and activity to some of the outermost Antarctic islands, especially the South Shetland Islands, at which numerous vessels gather during the summer months for whaling, still of high

[3] The Arctic Regions, as is known, in earlier times had a somewhat similar but now entirely exterminated form, the great auk.

economic value. It is estimated that for the year 1924–1925 the total production of whale oil in the Antarctic was over 700,000 barrels valued at about $20,000,000.

Man

No part of the earth is so completely devoid of human life as the enormous Polar Regions. Only the deserts can be compared with

Fig. 20—Landscape with Eskimos and relatively luxuriant vegetation in the interior of the coastal belt of western Greenland. (Photograph from the author.)

them. On some of the Arctic coasts of the western hemisphere lives, small in number, the only people that exclusively belongs to the polar world and that has adapted itself to its environment in a remarkable way. Here, thanks to the sea animals, especially seals, the Eskimos (Fig. 20) live sometimes in abundance, sometimes in need, but usually without too great difficulty.

That man is lacking in the true "polar desert" of Antarctica is perhaps a matter of course, and in the north the Eskimos are mainly at home in the transition zone with a vegetation of type (a), discussed above, from which, to be sure, in the case of the northwest corner of Greenland, they have spread into a region of strictly high-Arctic character. The larger land mammals and birds are everywhere zealously hunted, but as they are by no means sufficient as food, it became necessary to devise methods for hunting the sea mammals, especially seals. As native wood is everywhere lacking, the Eskimos

succeeded in building a seaworthy boat, the kayak, mainly of sealskin; they also developed a group of fishing utensils and invented fishing methods, some of which are exceedingly ingenious. Another example of adaptation to nature is their learning to use, in this land without wood, a material here everywhere at hand but probably employed nowhere else in the world—snow—to build their huts. Nothing could set many important features of polar nature in a clearer light than a description of the Eskimos and their way of living; but such a description lies outside of the scope of the present work.

Evolutionary History of Organisms in the Polar Regions

In order to understand the distribution and occurrence of polar organisms it is not enough to know their present nature; it is necessary also to know a little of their evolutionary history and their former conditions of life. Polar climate, which now so strongly stamps every feature of polar nature, has not always been the same as at present. In recent times, geologically speaking, there have taken place in these regions at least two revolutionary changes now evident both in the north and in the south. Earlier, and still in the middle Tertiary, the climate was warm or distinctly temperate. Later, during the early Quaternary, there took place the climatic deterioration of the Ice Age, during which conditions of existence for all organisms were still more unfavorable than at present. For a considerable time now the remains of a rich flora of warm-temperate forms have been known from the first-mentioned age in several Arctic countries, especially Greenland and Spitsbergen. The finding of a luxuriant Tertiary tree vegetation (Fig. 21) in the vicinity of the Antarctic Circle, where vegetation is now practically lacking, was an interesting result of the Antarctic expedition directed by the writer. The vegetation was related to forms that now live in South America—some of them in the warm part of that continent. Also it was found that as early as Tertiary time penguins were living on the shores of the Antarctic sea. These plant forms have evidently not the slightest relationship to the present scanty Antarctic vegetation. The natural conditions are entirely too different for this. But even in the Arctic, with its somewhat warm summers, there is no relationship apparent between the Tertiary flora and the present flora. Nor is it probable that the present flora is a direct descendant of the earlier. Between these two ages there was both in the north and the south a period with a still greater extent of ice than in modern times. This Ice Age has been discussed in an earlier chapter (Chapter III). As there pointed out, at least the lands of the Arctic could hardly ever have been entirely covered by ice. Even at that time a large part of the American

Arctic Archipelago was ice free. It is also fairly certain that glaciation in southern Greenland, for instance, never was more intense than it is at present in the Antarctic. Thus ice-free nunataks may always have existed there (southern Greenland), and on these a scanty vegetation may have survived in spite of the climate (see Fig. 22). Whether this really was the case is a much debated question. It is evident that very few plants could have adapted themselves to such extreme changes of climate, especially if the cold period came on fairly rapidly. But if it could be proved that all or nearly all higher plants died out, the summer temperature in southern Greenland during at least a part of the Ice Age must probably have been below 0° C. Then also this comparatively temperate outer Arctic belt would have had the same nature as the Antarctic at the present time and thus would have been essentially colder than, for instance, the northernmost part of Greenland today. Such an extreme deterioration of the climate has elsewhere not been accepted.

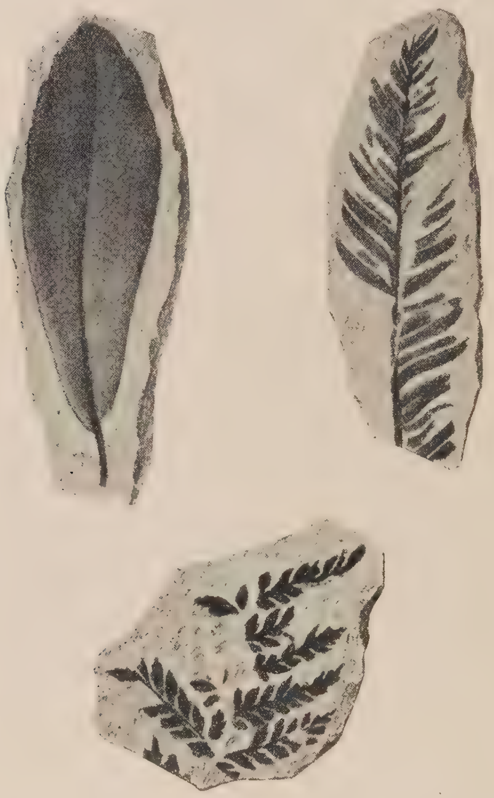


FIG. 21—Tertiary plant fossils, collected during the Swedish Antarctic Expedition and described by Per Dusén. Upper left, *Lomatia seymourensis;* upper right, *Sphaenopteris sp.;* bottom, undetermined fragments.

It seems also very unlikely to the writer that the cryptogamic vegetation died out during the Ice Age. It is much more likely that this was the case in the Antarctic, where ice-free land now has such a limited extent. As opposed to this view, however, strong endemism is now characteristic there of the extant poor flora. For instance, among the 63 known mosses, 27 species, consequently 43 per cent, and among these one genus, are exclusively found on the Antarctic Continent. Even if it be admitted that most of these have close relatives in the sub-Antarctic area, it seems, especially considering the fact that several of them are widely distributed within the Antarctic lands, very improbable that they would have had time to emigrate and by adaptation to the new conditions be changed to new

species during the short postglacial epoch. The climate itself cannot have prevented them from surviving, as the summer in the Graham Land region hardly can have been colder than it now is in South Victoria Land, where several species of mosses grow. It is therefore probable that here, even during the time of the largest extent of the

FIG. 22—Completely ice-covered land (Spitsbergen type) on the northwestern coast of Graham Land. Islands rising steeply from the sea are free of ice. Ice-free islands like these (nunataks) perhaps fringed the Norwegian coast at the time of maximum glaciation and afforded a refuge for vegetation. (Photograph from the author.)

ice, at least a trace of vegetation existed on the ice-free portions; and it must, then, be assumed that to a greater extent this was the case in Greenland.

CHAPTER VI

THE DELIMITATION OF THE POLAR REGIONS AND THE NATURAL PROVINCES OF THE ARCTIC AND ANTARCTIC

The most important features of polar nature have been dealt with in the preceding chapters. Just as the people of a foreign race at first all appear to resemble one another, while after closer acquaintance one learns to notice the individual differences, so it is with this strange nature. At first one sees only the main features—the cold, the ice, the scanty vegetation, etc.—that distinguish the Polar Regions from other parts of the earth. But the better we come to know them, the more distinctly the endless variety of this nature appears, and it becomes evident that these regions also can be divided into a number of natural provinces as characteristically differentiated as the natural areas in the temperate belts. The major contrast is between the Arctic and the Antarctic, as will be shown below, but even within each of these there are parts that differ greatly.

The Determination of the Limit of the Polar Regions

The question as to where are the limits of the Polar Regions is by no means easy to answer. These limits evidently should coincide with the occurrence of one or several of the chief features of polar nature discussed in the preceding chapters. Perhaps the best natural limit which comprises all features that can possibly be assigned to the Polar Regions is the polar tree limit. However, if this limit is chosen, a belt of undoubted transitional nature is included in the Polar Regions, whereas polar nature proper is first met with considerably nearer the pole, within the treeless regions, where perpetual ice is on the whole at least not far away. As for the climatic limit of the polar zones the mean isotherm of 10° C. of the warmest month of the year is usually adopted, after Supan's suggestion. In continental areas this line generally coincides closely with the limit of forests and agriculture, consequently with the tree limit. In maritime regions with cool summers and mild winters this line, on the other hand, does not hold. For according to this definition, the luxuriant and in part semitropical forests of Tierra del Fuego would be included in the Polar Regions, though they are inhabited by people that practically use no clothing and by parrots and humming birds. In order to avoid this apparent

paradox the writer proposed in an earlier publication[1] to include only the areas where the warmest month is colder than +10° C. and the annual mean temperature at the same time lies below the freezing point. The suggestion is evidently an approximation only, but it is a decided improvement. In the northern hemisphere it does not cause any change; in the southern the limit becomes, on the other hand, much more natural.

Lately, however, important studies by Martin Vahl have given a better basis for a discussion of the relationship between climate and flora, the former expressed in its principal factor, summer and winter temperatures, and in some cases precipitation. The different influences of the two first-mentioned climatic factors have been expressed by Vahl in the formula

$$v = a + bk$$

where v represents the temperature of the warmest month and k that of the coldest month and where a and b are constants that have to be determined in each case. Vahl has not determined the precise course of the limit of the Polar Regions, but, as he seems to let it coincide with the tree line, he regards the equation

$$v = 9.5^\circ - \frac{1}{30} k$$

as the most favorable for the determination of the position of this boundary. However, neither of these equations suits the conditions in the southern hemisphere, where it is necessary to choose a limit in such a manner that, for instance, Staten Island off Tierra del Fuego, which has a warmest-month temperature of +8.9° and a coldest-month of +2.5° C., will fall well within the temperate zone. This makes it necessary for the coldest month to be taken into greater consideration. It appears to me that the formula

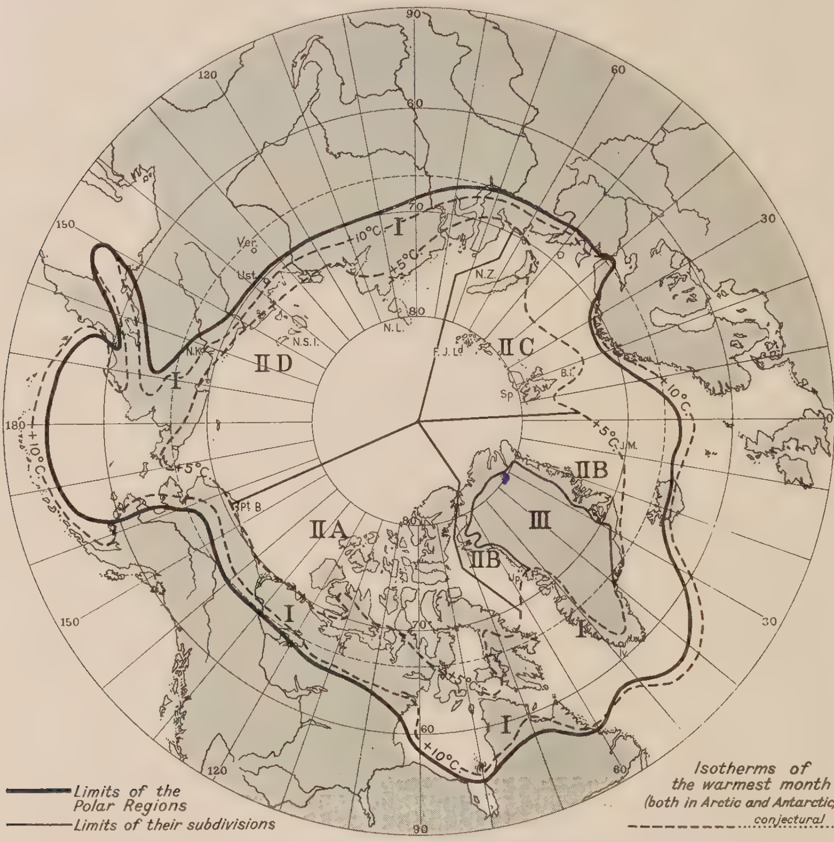
$$v = 9^\circ - 0.1\ k$$

is a more natural and in reality a rather acceptable limit.[2] This formula means consequently that, if the coldest month is 0° C., all areas with less than 9° during the warmest month are assigned to the Polar Regions. If, on the other hand, it is −10°, the corresponding limiting temperature of the warmest month is +10°, and if, as in Siberia, the coldest month sinks to −40° the highest summer temperature must rise to +13° C. before the region can be included in the temperate belt. I have so far made no attempt to calculate in detail the position of this line; but it is evident that according to this formula the greater part of Iceland, but not the northernmost part of

[1] Polarvärlden och dess grannländer, Stockholm, 1907; German edit., pp. 101–102 (for title of this edition, see p. 90 in the Bibliography below).

[2] Of course, this is only a rather rough approximation, but it seems to produce a better position of the boundary than the previous attempts.

Scandinavia, not even Fruholmen at North Cape, should be included in the Polar Regions. On the other hand, the northernmost Arctic Sea coast of European Russia falls outside the temperate belt. The same is the case with the increasingly wider coastal belt of Siberia and North America. In spite of its extremely cold winter Verkhoyansk is to be assigned to the temperate belt. Ustyansk (see Fig. 1), situ-

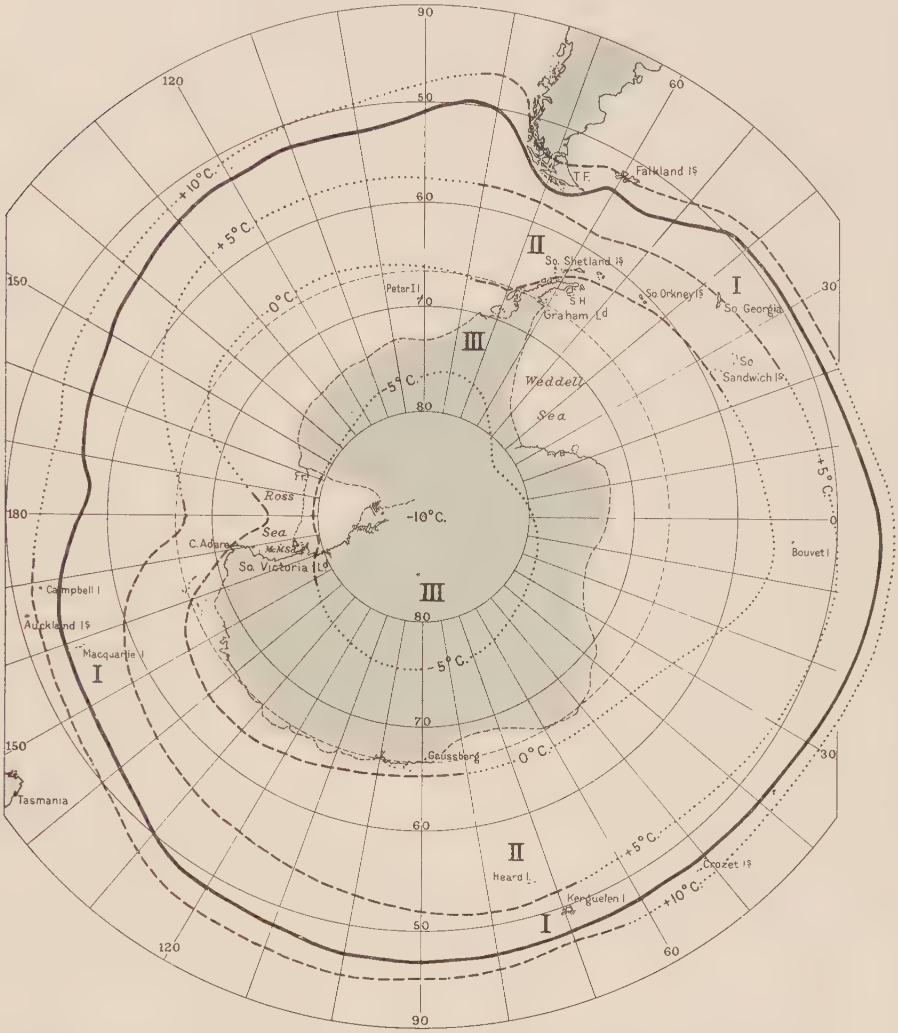


FIGS. 23–24—Maps of the natural provinces of the Polar Regions. Being on the same scale, 1:83,700,-000, both maps are directly comparable as regards space and size relations. The Antarctic map necessarily covers a greater area because of the greater extension of equivalent phenomena in the Antarctic than in the Arctic.

The outer limit of the Polar Regions is laid down according to a modification of Vahl's formula (see p. 73) expressing relationship between climate and vegetation. Within this limit the land in the Polar Regions is divided, mainly on the basis of the mean temperature of the warmest month, into three major provinces: I, Outer Polar Belt; II, High-Polar Belt; III, Antarctic Province. The Arctic representative of II, the High-Arctic Belt, is subdivided into: A, the greater part of the American Arctic Archipelago; B, the northern part of the border of Greenland; C, the North Atlantic polar

ated almost 400 kilometers due north and having a January temperature of −41.4° and a July temperature of +10.4°, is polar, while Nizhne Kolymsk lies on the July 10° line itself. In Greenland Ivigtut similarly lies on the boundary; and it is possible that an insignificant

area at the heads of the fiords of southern Greenland should be regarded as temperate, which also agrees rather well with the other natural conditions. In the southern hemisphere, of course, the whole



islands; D, the outermost fringe of the Arctic coast of Siberia and its offshore islands. Types I and II are not represented in the Antarctic except for a number of isolated islands; type III, except for the inland ice of Greenland, is not represented in the Arctic. Types II and III together may be considered to constitute the inner Polar Regions proper.

The isotherms shown indicate the mean temperature of the warmest month in C°; their position is of course approximate only. Abbreviated names refer to places mentioned in the text.

of Tierra del Fuego remains temperate,[3] and this holds true also of the Falkland Islands, although they lie near the limit. On the other hand,

[3] The observed temperatures in Orange Bay and at Cape Horn, however, according to this basis of calculation are very close to or even outside of the limit of the temperate zone.

South Georgia and Kerguelen fall well within the polar zone. These studies should evidently be carried further; but it ought now to be possible, in accordance with this principle, to indicate fairly closely on a map the natural limits between the Arctic and the north-temperate and between the Antarctic and south-temperate zones respectively.[4] It is to be expected that these limits will not coincide with the tree line in all respects, since a series of investigations shows that this line to a large extent is influenced by water supply and evaporation and perhaps by other conditions.

The Three Main Belts of the Polar Regions

Within the Polar Regions as thus delimited three main belts may be distinguished on the basis of summer temperature, which in this zone almost exclusively determines the vegetation; their extent is evident on the two maps, Figures 23 and 24. In the first belt, whose warmest-month temperature lies between $+10°$ (with small deviations, of course, as outlined above) and about $+5°$[5] bush vegetation is still to be found and close plant associations prevail. In connection with this it is possible, at least within the warmest part of the belt, to carry on reindeer breeding and in favorable instances even to keep other domestic animals, especially sheep, which graze out of doors during the summer. Agriculture, on the other hand, is not carried on.[6] Ice cannot remain here on the lowland or accumulate in the vicinity of sea level, although of course the large mountain glaciers frequently extend down that far. To this belt, which is of an intermediate character, belong chiefly the greater part of the continental tundra regions of Asia and America and the strip on the European Arctic seacoast mentioned above, as also evidently parts of the American Arctic Archipelago. Here belongs, furthermore, the greater part of Iceland, in which the comparatively mild winter fosters extensive animal husbandry. In the southern hemisphere this whole belt is hardly developed at all. To it belong a few oceanic islands only, Kerguelen primarily and South Georgia also, on the latter at least the lowland at the heads of the fiords (warmest month about $+5.5°$ C.). In the north a large part of the coast region of Greenland, in the east up to latitude 65° and in the west up to 72°, must furthermore be included here. On account of the vicinity of the inland ice

[4] An attempt in this direction has been made on the maps, Figs. 23 and 24, but of course too much should not be expected of them. The scale is entirely too small, and I have not had opportunity carefully to go over the material of detailed observations, as should be done for the boundary regions. The maps, however, give some idea of how this boundary line and the warmest-month mean isotherm of $+10°$ are related to each other.

[5] In the American Arctic Archipelago this limit according to the usual climate charts seems to coincide with the July temperature of about $+4°$, but presumably this coincidence is only apparent, as the temperature in the interior, about which we are here concerned, is certainly higher (cf. the map, Fig. 23). Gunnar Andersson has suggested as the limit of this zone the July isotherm of $+6°$.

[6] Only in the southern margin of Iceland is rudimentary agriculture practiced.

and the very low temperature of the sea and also because this coastal belt itself consists to a large extent of high mountain land, nature here exhibits a peculiarly mixed character. Nevertheless this area should not be excluded here, although the present work refers primarily to the next two, inner, belts, which constitute the Polar Regions proper. This mixed character of the Greenland coast makes it easier to understand the strong contrasts which also in certain interior areas, at least in the Holsteinsborg District studied by the writer, produce a climate of evident transitional character. For a study of the contrasts presented by polar climate no region is more interesting than Greenland; but the inhabited regions of the southern half of its coasts cannot be taken as typical of a real polar climate.

Within the limit where the mean temperature of the warmest month rises to +5° C. (cf. map, Fig. 23) fall the two areas which are usually considered to constitute the Polar Regions proper. The first of these extends to the line formed by the isotherm of 0° C. during the warmest month and thus actually comprises all remaining Arctic coastal lands.[7] It therefore can suitably be characterized as the high-Arctic belt. High-growing bushes are no longer to be found here, and vegetation as a continuous cover (grass tundra) is present only at especially favorable places. As a rule the plants appear scattered and separated by bare spots. Many species form cushions or are otherwise adapted for protection against the severity of the climate. In but few places (on Inglefield Gulf in northwestern Greenland and in certain parts of the American Arctic Archipelago) does a permanent population live in this belt at the present time, and there is no form of cattle raising here. Large grass-eating animals, however, occur almost everywhere within the zone, and it can be said that the limit of the phanerogam vegetation approximately coincides with the poleward limit of this zone. In a region with such summer temperatures small glaciers can form, if not at sea level at least at elevations of a few hundred meters and upward, practically everywhere in wind-protected places where during the winter large snowdrifts accumulate. The highlands are as a rule largely ice-covered; and the glaciers, occasionally of very large dimensions, extend from them to the sea and there break up. Under normal conditions the lowlands, however, are ice-free during summer, and in regions with little precipitation large areas can be fairly free from ice. To this zone are to be assigned the marginal parts of Greenland not included in the preceding belt and also Bear Island, Spitsbergen, Franz Josef Land, and Novaya Zemlya. The latter island, however, partly forms a transition to the outer zone. Of the continents only isolated parts of the very outermost coastal rim of Asia and America belong here;

[7] In this classification we therefore group together the two vegetation zones (b) and (c) (see, above, p. 65), as, in the present state of our knowledge, it is still very difficult to distinguish between them.

while the American Arctic Archipelago, except its southern part probably, falls within this zone.

The practical absence of this zone in the southern hemisphere except for a few insignificant oceanic islands (Heard Island, in the latitude of northern Germany, may have a summer temperature of about +3° C.) is one of the outstanding traits in the distribution of the great geographic provinces of the globe. On protected places in the northernmost South Orkney and South Shetland Islands also the mean temperature during the warmest month may reach somewhat above the freezing point; and, slight as is this temperature increase, it at once becomes noticeable by producing a somewhat richer vegetation.

With these exceptions the whole Antarctic Continent with the surrounding islands belongs to the third large polar province, which may properly be called the Antarctic, since no corresponding climate or nature has been found at sea level in any Arctic land area. Therefore a description of the nature of the northern and the southern representative of this province in reality becomes a treatment of the distinction between Arctic and Antarctic nature in general. Because of the great interest of this problem it will be touched upon briefly, without confining the discussion to the characteristic features directly caused by climate and related factors. In this general comparison some of the characterizations already made may have to be repeated here.

Comparison Between Arctic and Antarctic Nature

The climatic differences have already been discussed at some length. There may not be any great differences between the mean winter temperatures in the north and the south at the same distance from the poles. The same may also hold for the spring. On the other hand, winter temperatures begin earlier in the Antarctic. The autumn is very cold. The chief difference lies in the summer temperature, which in the south does not even stop at 0° C. Thus, for instance, the observed temperature of the warmest summer month at Amundsen's station was about −7°. In addition there is the strength of the wind, which generally seems to be much greater in the south than in the north. Therefore on the whole the climate here is, if not always colder, at least much more severe than in the Arctic Regions.

It is, however, chiefly these low summer temperatures that are the direct cause of most of the very striking features that make the whole character of nature so different in the north and the south. First come the ice conditions. In the north there are, still within the high-Arctic belt, especially within the American Arctic Archipelago, land areas probably totaling about 1,000,000 square kilometers, that are not covered by continuous ice: this is the case even with the very northernmost known lands of the earth. Where the precipitation is

FIG. 25

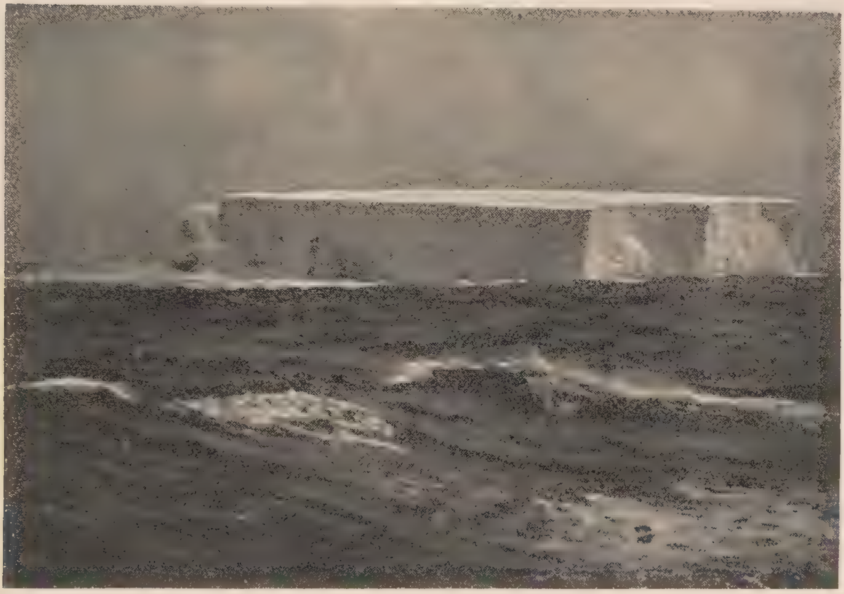


FIG. 26

FIG. 25—Irregularly formed icebergs of Arctic type. Entrance to fiord at Godthaab, western coast of Greenland. (From a postcard view by J. Möller.)

FIG. 26—A tabular iceberg of Antarctic type. (From Carl Chun's "Aus den Tiefen des Weltmeeres," Gustav Fischer, Jena, 2nd edit., 1903, plate opp. p. 208.)

insignificant these summer temperatures are generally sufficient to melt the snow that falls during the winter. Other enormous areas are covered by inland ice or by glaciers of the Spitsbergen type; but continental ice masses formed on the lowlands are lacking, and the inland ice normally is limited to the higher interior and only exceptionally and in places reaches the coastal belt. It is entirely different in the south. Here the inland ice almost everywhere extends beyond the coast into the sea, and here, in shallow waters not occupied by

land ice, enormous ice fields of peculiar type appear (shelf ice).[8] Ice-free land generally occurs in the shape of nunataks (ice-surrounded rocks) and narrow strips and steep slopes in some coastal regions. Characteristic of the Antarctic, even if not limited to that area, is also the narrow belt of ice (ice foot) which, for long stretches of the seaboard, follows otherwise ice-free mountains.

On account of the direct solar heating of the ground, the Antarctic low summer temperatures cannot eliminate all organic life, though these and the insignificant extent of ice-free land have developed far less advanced forms in the Antarctic than in the high-Arctic area. Whereas the northernmost coast fringes of the earth are covered by a rather rich vegetation, only two flowering plants have been found in the Antarctic proper, both of which grow outside the Antarctic Circle in the warmest outermost parts of West Antarctica; and mosses and lichens are also comparatively scarce, both as regards number of species and number of individuals (cf. Figs. 15 and 16). In this connection it should be remembered that the outermost part of the Antarctic province lies much nearer the equator than any part of the high-Arctic area. It is therefore quite natural that grass-eating animals should be entirely absent in the south, while the very northernmost lands are inhabited by such large and highly developed mammals as the musk ox and the reindeer. But not only all predatory animals but also practically all real land animals are lacking in the south. The largest form, a four-millimeter-long wingless mosquito (*Belgica antarctica*), occasionally found in particularly favored localities in the same latitude as central Sweden, is an extremely stunted counterpart to the rich fauna with billions of swarming mosquitoes in the northernmost lands in the high-Arctic area.

For a comparison between the flora and fauna of the south and that of the north, however, there must be taken into consideration not only the surrounding nature but the whole evolutional history of the organisms. It is evident that life must be more abundant in an area having direct land connection with the warm and temperate parts of the continents than on the completely isolated Antarctic Continent, especially as during the Ice Age it was more heavily ice-covered than now. On the other hand, the difference is essentially less in regard to the marine life and the animals which, though dwelling part of the time on land, find their nourishment in the sea. To this group chiefly belong the seals and water birds. Whereas in this group the number of species are fewer than in the Arctic, this hardly holds true for individuals. Furthermore, the penguins, strange and striking in appearance, give the Antarctic bird fauna a character quite distinct from the Arctic.

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[8] The shelf ice and the Antarctic inland ice that extends on a broad front into the sea produce extensive, flat, table-shaped icebergs, very unlike the irregular Arctic bergs (see Figs. 25 and 26).

In this connection it may be pointed out that one of the most pronounced contrasts between the Arctic and Antarctic Regions lies in the fact that the former have the Eskimos whereas the latter never had any permanent indigenous population.[9]

The Subdivisions of the High-Arctic Belt

In this brief summary of the typical features of the three main zones of the Polar Regions each belt has been discussed as a unit. Evidently one might go a step further and attempt to divide these main zones into smaller areas. As regards the outer Arctic belt its treatment lies somewhat outside my subject; and I will therefore not dwell on it any longer here, but it may be stated that at any rate the continental American and Siberian regions in this belt differ greatly from the coastal regions of Greenland. Neither will any detailed division of the Antarctic province be attempted: it is so uniform that this is hardly necessary. On the other hand, the high-Arctic zone, to which most of Greenland may be assigned for practical reasons, presents very pronounced contrasts in its different parts; and in conclusion a brief treatment of the nature of its subdivisions will therefore be given. Their approximate extent has been tentatively indicated on the map, Figure 23.

The first of these subdivisions comprises the American Arctic Archipelago, with the exception of the southernmost portions of Baffin Island and Victoria Island, which, because of the occurrence of willow bushes and "southerly" plant forms, should be included in the outer Arctic belt, though, to be sure, there is no sharp boundary. On the other hand, some small protruding parts of the North American continent should be included in this subdivision. The major part of the American Arctic Archipelago as thus outlined is the largest land mass in the high-Arctic area with the exception of Greenland. The warmest month, July, has on the coast a temperature between +2.5° and +5°. The temperature of the coldest month lies between –25° and –40° C. and is consequently less severe than within large parts of the outer zone in continental Asia. The climate in the American Arctic Archipelago is thus less continental than in Siberia, presenting in both summer and winter less pronounced extremes. Furthermore, the precipitation is insignificant both in summer and winter; and perhaps closely related to this fact is the circumstance which, more than any other, is characteristic of the nature of this region, namely that the distribution of ice has a limited extent as compared with all other regions of the earth having as low a summer temperature. To be sure, extensive ice fields and glaciers are to be found

[9] Some photographs illustrating the differences between Arctic and Antarctic nature are given in my work "Polarvärlden," pp. 88–89 (German edit., pp. 74 and 86–87). See above Figs. 25 and 26.

in the mountain regions on the eastern margin of the Archipelago, but large areas of low land or land a few hundred meters high are free from ice and snow during the summer and often also during the winter. Unfortunately, good observations on the distribution and types of the ice are so far insufficient. It should be stated that there is no evidence that the extent of the ice formerly was much greater than now. On the other hand, a large part of the low coastal regions, up to an altitude of about two hundred meters, was covered by the sea during the Quaternary period. In both Baffin Island and Grant Land, in the latter in latitude 82° N., large fresh-water lakes have been found in the interior. The vegetation is comparatively rich. The number of flowering plants in the whole Archipelago is reported by Simmons as about two hundred, of which some are limited to the southernmost, not fully high-Arctic parts. In the northernmost parts the vegetation in the interior has a rather luxuriant aspect, possibly because of considerably higher summer temperatures than are usually assumed. The animal life is also relatively abundant. Reindeer and musk oxen, for instance, occur all the way up to the northern coasts, and the insect fauna is rather plentiful. Part of the area is inhabited by man, a few thousand Eskimos still living on Baffin Island and in the southern parts of some of the western islands. Formerly, the coasts of almost the whole Archipelago up to latitude 83° were inhabited.

The second large subdivision of the high-Arctic zone is the immense land mass of Greenland.[10] It has already been stated that this island, extending from the latitude of Stockholm nearly to 84°, presents widely different climatic conditions in various parts of its coastal regions. In the south these are not high-Arctic but in part rather temperate. However, by far the greater part of the land is, both with regard to its general character and to its climate, distinctly high-Arctic or rather to a great extent Antarctic, the inland ice causing the only real similarity between the North and South Polar Regions. The temperature during the coldest month varies between −7° on the outer islands at the southern end of the country and −35° to −40° at the northwestern coast. During the warmest month the temperature in the latter area, as well as on the east coast north of latitude 75° N. is as low as +3° or +4°. At the southern end of Greenland the temperature during this season is greatly influenced by distance from the sea. To a temperature of +4° on the outermost skerries corresponds a temperature of +10°, or locally possibly still more, in the ice-free interior. Apparently, therefore, the temperatures on the coastal belt are very irregularly distributed. As far north as

[10] On the map, Fig. 23, the major part of Greenland, the inland region, rightly appears as belonging to the third, Antarctic, type. This region is here included in the discussion of the high-Arctic belt, apart from the practical reasons, partly because of its mixed character, partly for the sake of better comparison.

Jakobshavn, near latitude 70°, the July temperature is still +7.7°. On the inland ice considerably lower temperatures prevail both summer and winter. About these little is known, however. The precipitation in southern Greenland is heavy, amounting to almost 1200 millimeters in the fiord at Ivigtut. But in northern Greenland, and especially on the east coast, it is fairly small. The summer here particularly is dry.

In Greenland also the occurrence and distribution of the ice is the most striking feature, but in this case it is the exceptional extent of ice that is characteristic. It is still an unsolved problem how inland ice of such dimensions can arise and exist in an area where the summer temperature is so high as at the ice border in southern Greenland. To be sure, southern Greenland is a highland with heavy precipitation, but this does not explain everything. There may be two causes. One is the free direct land connection with the northern Greenland land mass, whose climate is distinctly high-Arctic and must have been still more so during the Ice Age, whereas the precipitation may be higher than on the American Arctic Archipelago. Once formed, the ice both with regard to temperature and condensation produces favorable conditions for its own expansion. But also another view is possible: the arid climate with warm summers that now prevails at the ice border is not that which normally would prevail in the interior of Greenland if the ice did not exist, and it may in some way be due to the ice. The very different climate now found in the skerries of southern Greenland, which is especially favorable for the formation of ice, is perhaps more characteristic of the area. As is well known, not all Greenland by any means is ice covered; the more or less wide coastal zone, comprising nearly 300,000 square kilometers and consisting of both high and low lands, is relatively free from ice. Outstanding among these are the ice-free areas on the north coast of Greenland, where the climate may be especially dry and which in their character more nearly resemble the American Arctic Archipelago province to the west. Earlier, however, the ice was considerably more widespread and covered the greater part of the existing lowlands. Later, on the other hand, the climate for a time was milder than today.

The vegetation in Greenland of course differs considerably in the various parts of the island. In protected places at the heads of the fiords in the southernmost parts there are real forests, and even beyond latitude 70° N. a luxuriant bush vegetation with heaths and meadows is occasionally found. The relative scantiness in the interior of Holsteinsborg with its warm summers may be largely due to a pronounced drought. Greenland contains about 420 species of known vascular plants. The flora is apparently richest in southern Greenland, but even up to latitude 70° the number of species is large, whereas hardly 100 vascular plants are known from the whole large area

north of Melville Bay. The fauna also far up in central Greenland is by no means as meager as one might expect in a high-Arctic land. Musk oxen exist only in northern Greenland; but the reindeer, which formerly were so numerous that about 25,000 could be killed annually, are, though rapidly diminishing, to be found here and there in large herds. Land birds are present in large numbers; the insect fauna also is rich, about 440 species being known, the majority of which are flies and mosquitoes. As for the mosquitoes, a single warm summer day is sufficient to give a lasting and disagreeable impression that the insect life in the neighborhood of the land ice is second to none in point of numbers anywhere on the globe. About 50 species of butterflies, among them a few day butterflies, exist as far up as northern Greenland. Numerous beetles and spiders and some species of bumblebees are also found. Associated with this varied nature and with its location near a sea that is not ice-covered for too long a period, is the well-known fact that Greenland is the most populated polar land. On the west coast Eskimos live all the way up to altitude 78° N., and in earlier times the coast was everywhere inhabited. At the present time also a fairly large European population dwell there.

The North Atlantic polar islands may be called the third subdivision of the high-Arctic zone. It includes chiefly Spitsbergen with King Karl Land and Franz Josef Land and, furthermore, Jan Mayen and Bear Island. On the other hand, Novaya Zemlya forms a transition area which can as well be assigned to this as to the outer belt. A part of its west coast and its southern part have a higher summer temperature than +5° and are therefore not strictly high-Arctic. In contrast to the extensive land masses of the two preceding subdivisions, we have consequently to deal here with a number of small isolated islands whose members furthermore differ from one another. The climate becomes more and more continental as one proceeds towards the east, the winter temperature sinking from −10° in Jan Mayen and −20° in Spitsbergen and Novaya Zemlya to −27° in Franz Josef Land. The July temperature as a rule lies between +3° and +5° but sinks in Franz Josef Land to +1.5°. The precipitation in Jan Mayen amounts to nearly 500 millimeters, in Spitsbergen it is much less. Contrary to what might be expected, there is no specially great accumulation of ice on the islands owing to the maritime character of the climate, which is the result of their position in a sea that is only partly ice-covered. On Bear Island ice is lacking, and on Jan Mayen all lowland is ice-free. This latter statement also holds for a great part of the plateau land on the large fiords of West Spitsbergen. The rest of Spitsbergen is largely glaciated; but only on the comparatively low Northeast Land does real inland ice, or a very similar type, exist. Franz Josef Land, as the temperature suggests, is almost entirely ice-covered except for nunataks and coastal cliffs. In elongated Novaya

Zemlya glaciation decreases greatly as the temperature rises. The northernmost part of the northern island is covered by continuous ice, probably of the Spitsbergen type. The southern island south of latitude 73° N., in spite of an altitude of as much as 600 meters, has only a small isolated glacier of the Norwegian type.

The vegetation is on the whole poor in the whole area. In Spitsbergen there are, however, about 125 vascular plants, and on protected spots the flora can be fairly abundant. In the whole of Franz Josef Land, on the other hand, only about 25 of the hardiest species have been found.

The fauna of Spitsbergen is poorer than that of Greenland; of larger land animals it contains, however, the reindeer. It is significant that none of these islands ever was inhabited by a permanent indigenous population.

In some respects it might be well to distinguish a fourth subdivision within the high-Arctic Region. This subdivision would comprise some small northern Asiatic islands, primarily the New Siberian Islands and the lately discovered Nicholas II Land (Northern Land). It would, furthermore, comprise the parts of the coast of Siberia along the Arctic Sea that have the lowest summer temperature, especially the northern part of the Taimyr Peninsula, in which the tundra vegetation is particularly scanty over large areas and unable fully to cover the ground. Gyda Bay, west of the mouth of the Yenisei River, in latitude 72½° N., has a July temperature below +2° C., in spite of which, however, the tundra is covered with flowers during the summer and mosquitoes and other insects thrive there. Both as regards the low winter temperature and the insignificant extent of ice, the area greatly resembles the American Arctic Archipelago. Differences do exist, but there is no special reason to enter upon them here, inasmuch as the area is of no great extent and is comparatively well known.

Disregarding consequently this northern Siberian region, the three others can be briefly characterized as follows: The American Arctic Archipelago—cold winters, slight precipitation, insignificant distribution of ice both now and during the Ice Age, vegetation poor in species but in the south quite luxuriant, several large land animals, and Eskimos in the southernmost parts. Greenland—very large climatic contrasts between the southern and northern ends, but within the coastal belt, except farthest north, mostly rather mild winters and not particularly cold summers, exceptionally heavy glaciation, which was still more extensive during the Ice Age, relatively rich vegetation all the way to the northern parts, abundant animal life, and the densest population in all the Polar Regions. The North Atlantic polar islands—winter temperature becoming lower from west to east but everywhere relatively mild, decreased vegetation and increased glacia-

tion in the same direction, relatively meager animal life, indigenous population lacking.

If the two polar types at the opposite ends of the classification be added, namely the Antarctic type and the transition belt along the southern border of the Arctic, we find that the Polar Regions, like other land areas of corresponding size, are far from uniform and that here also contrasting regions alternate with each other in close proximity.

CONCLUSION

We have now reached the end of our inquiry, and the results obtained should be briefly summarized.

For those who live in northern countries polar nature is not so foreign as one may believe when one reads or hears of Peary's or Amundsen's adventures and journeys to the poles. Every dweller in the North has at some time experienced a winter day when the storm was raging and the cold was severe, when snow and ice smoothed out and concealed the contours of the landscape, shrouded in darkness, and when the dormant vegetation seemed practically to have disappeared from the scene. He has also to some degree learned to know some of the most important features that characterize polar nature even if they are all more intensely developed in the Polar Regions than in his surroundings. But polar nature has still another side which we, in temperate regions, have great difficulty in realizing, namely the character of the summer, with its long, bright days of intense yet heatless sunlight, with its sparse vegetation, and with its patches of snow and ice still visible here and there in the landscape.

The climate, the ice covering, and the sparse vegetation are the three main factors that make polar nature what it is. Among these climate is fundamental, as in its variety it produces the other two and the contrasts which they present. Thus the ice may appear under many different forms or be entirely wanting over large areas, even in the inner part of the Polar Regions. The vegetation exhibits no such diversity and may even outwardly appear to be characterized by uniformity, but the species vary in different regions and so does still more the number of individual plants, until nearly all higher vegetation disappears. With respect to the climate, regard must always be had to both summer and winter temperatures, although the first-mentioned is by far the most important. It is of comparatively little importance to plants, animals, and man whether the mean temperature of the coldest month is $-20°$, $-30°$, or perhaps $-45°$. Precipitation and velocity of wind are also of a certain importance. Besides these there are a number of other factors that contribute to the character of polar nature, for example, change in the conditions of light between summer and winter, the fauna, certain features in the landforms, etc.; but these are subordinate in comparison with those already mentioned.

It has not been our object in the present work, as has been done so often before, to pick out a few typical features here and there and combine them into a general picture of the theoretical natural

conditions that might be assumed to exist in the Polar Regions and that ought to distinguish them from other parts of the globe. On the contrary the intention has been to study these features in their diversity from region to region and in their relation to each other, with a view to determining how great the contrasts in reality are even within these parts of the globe, and to cap this study by an attempt to divide the Polar Regions on a scientific basis into their natural provinces. The division into three major belts with progressively decreasing summer temperature—two developed in the Arctic almost exclusively and the third dominating the Antarctic—is by no means new; but I have tried to shed new light on the problem and have also attempted especially to subdivide the central, high-Arctic, belt into its natural regions.

Finally, an attempt has been made to go a step farther and to apply the experiences from the Polar Regions to areas that have still greater interest for us. Immense parts of the globe that are now temperate previously experienced polar conditions, and the problem is to apply to those parts the knowledge gained through modern polar research and thus obtain a better idea of the real situation at that time, and to determine the magnitude of the actual changes, both those that caused the glaciation and those that were its consequences. In connection with this some of the more disputed topographic features due to the Ice Age have been treated, and the cause of this remarkable age in the earth's history has also been dealt with.

However, only a few aspects of modern scientific polar research have been touched upon here. Very much still remains to be done in this field, both by new expeditions to the Polar Regions, during which special efforts should be made to secure long-period observational records of all kinds, and by a more thorough analysis of the observations of earlier expeditions.

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PART II
REGIONAL GEOGRAPHY

Dr. MECKING was formerly a pupil of Ferdinand von Richthofen, subsequently becoming *privatdozent* at the University of Göttingen and professor at the University of Kiel, and is at present professor of geography at the University of Münster. Although his work has dealt with all branches of geography, he has devoted himself especially to polar geography, oceanography, and climatology. His "Eistrift aus dem Bereich der Baffin-Bai beherrscht von Strom und Wetter" (*Veröffentl. Inst. für Meereskunde an der Univ. Berlin*, No. 7, 1906) was an initial study to determine with precision the comparative effect of wind and currents upon ice drift. This was followed by "Die Treibeiserscheinungen bei Neufundland in ihrer Abhängigkeit von Witterungsverhältnissen" (*Annal. der Hydrogr. und Marit. Meteorol.*, Vol. 35, 1907). Together with Wilhelm Meinardus he prepared the meteorological atlas in the series of scientific reports of the German Antarctic Expedition of 1901–1903 and also contributed to that series "Die Luftdruckverhältnisse und ihre klimatischen Folgen in der atlantisch-pazifischen Zone südlich von 30° S. Br." (Vol. 3, Part I, No. 1, Berlin, 1911). On the Antarctic he has also written "Der heutige Stand der Geographie der Antarktis" (*Geogr. Zeitschr.*, Vols. 14 and 15, 1908–1909); "Zum antarktischen Klima" (*Petermanns Mitt.*, Vol. 55, 1909); on sea ice, "Das Eis des Meeres" (*Meereskunde*, Vol. 3, 1909); and on the Polar Regions in their entirety, "Die Polarländer," Leipzig, 1925 (the book of which a translation follows), and "Die Polarwelt in ihrer kulturgeographischen Entwicklung, besonders der jüngsten Zeit" (*Geogr. Zeitschr.*, Vol. 31, 1925). Among papers that reflect his interests in other branches of geography may be mentioned "Benares, ein kulturgeographisches Charakterbild" (*Geogr. Zeitschr.*, Vol. 19, 1913) and "Von Singapur bis Yokohama" (*Meereskunde*, Vol. 7, 1913).

THE POLAR REGIONS: A REGIONAL GEOGRAPHY*

Ludwig Mecking

PREFACE

Polar exploration has made astounding progress since the end of the last century. Expeditions in the Arctic as well as in the Antarctic have made fundamental discoveries and achieved palpable and immediate results, besides bringing back a wealth of observations for scientific analysis and the advancement of knowledge. The many recent volumes of scientific reports and the series *Meddelelser om Grönland* bear witness to this fact. Ample material is therefore on the whole now available for the preparation of a regional geography of the Polar Regions. However, it is still quite uneven for different regions. An attempt to characterize the various regional units in their individuality will therefore hardly meet with a uniform measure of success. Nevertheless this ideal of regional geography underlies the plan, organization, and method of the present work. In portraying the Polar Regions the fundamental traits of the polar world as a whole, both in the Arctic and in the Antarctic, have constantly been kept in mind. The sea is often a fundamental part of this whole. The polar lands, in the north surrounding the relatively small basin of the Arctic Sea, in the south on the other hand surrounded by a ring of icy waters, are especially intimately associated with the sea, its ice and its temperature, its currents and its sources of food for man and animal; and this has been taken into account. With regard to the Arctic lands it would have been dogmatic to limit the description to the archipelagoes, for the connection of the lands of polar character with the margins of the mainland is so intimate that, for instance, on the American side the three major continental members, Alaska, the Barren Grounds, and Labrador, are either distinct units by themselves or else their marginal belts belong to the same units as the archipelagoes in climate and tundra character, in the distribution of the Eskimos and the animals that they hunt, as well as in the history of their discovery or their economic utilization by the white man. Continental margins therefore, to the extent that they are polar in nature, were necessarily included in the description, at least as transi-

* Translated by the editor, except the section on Greenland, from the author's "Die Polarländer" (in the new edition, edited by Hans Meyer, of the series "Allgemeine Länderkunde" originally edited by Wilhelm Sievers), Bibliographisches Institut, Leipzig, 1925.

tional areas. With regard to the history of discovery an attempt has been made to treat it in a manner possibly more suited to the Polar Regions than has been done heretofore, by not recounting it in detail at the beginning in the form of a separate historical discussion but rather by weaving its individual episodes into the regional description and thus leaving room in an introductory section for the exposition of the major fundamental traits of this history. Many an event in the history of discovery, such as Amundsen's completion of the Northwest Passage or the early discovery of West Spitsbergen, and many other matters that concern the development of exploration and its method can only be completely understood on the background of the natural conditions, and they in turn set off these conditions more vividly and may therefore be considered to belong in a regional synthesis quite as much as does a phenomenon relating to economics or to human geography.

The invitation of the publishers to undertake this work I did not accept without hesitation, for my own experience of polar nature is limited to a short sojourn in and around Spitsbergen. On the other hand my research work for the last twenty years has to a great extent been concerned with the climatic conditions of the Polar Regions and may thus possibly supply a not unimportant qualification, because in the geography of hardly any other part of the earth is climate so fundamental a trait as in the Polar Regions.

For the use of photographs I am indebted to the courtesy of Messrs. Erich von Drygalski, Arnold Heim, J. P. Koch, and Otto Nordenskjöld; furthermore to the library of Justus Perthes in Gotha for the ready willingness to supply material now often lacking in German state libraries.

LUDWIG MECKING

Münster (Westphalia)
October, 1925

THE ARCTIC

The Region As a Whole

Arctic Exploration: Its Course and Its Methods

PERHAPS no other scientific investigation requires such an equipment of technical resources and especially so much courage, persistence, and virility as the exploration of the Polar Regions. Mankind has conducted a gigantic battle for the unveiling of those regions, and nothing else affords a better conception of the majesty and spirit of polar nature than this struggle to uncover its secrets.

Early in history we see in the North men who lifted little by little the veil of fog, ice, and winter night from those lonely lands and seas, often at the cost of great suffering from hunger, cold, and scurvy. In this search there were from the beginning three fundamental incentives: the urge to be the first to see and report the unknown; the desire to measure one's strength against danger; and the prospect of some sort of gain. And to this day the penetration of the realms of ice is carried on as science, art, sport, and economic service, even though the striving for knowledge as such is now the leading motive.

The men of antiquity had reached the gateway of the Arctic Regions in that daring voyage which Pytheas of Massilia in 325 B. C. made beyond Britain to the inhabited land of Thule, probably Norway, where the sunrise followed sunset by a short interval. Other than this, the Greeks were acquainted, theoretically to be sure, with certain fundamental physical characteristics of the Polar Regions, but they knew nothing else about the northern lands and seas. The disclosure of their general outlines was to be the work of the northern Teutonic peoples in the Middle Ages. After Pytheas' landfall, the first to reach the White Sea was the Norwegian noble, Ottar, in the ninth century. More important, however, was the establishment of a foothold on Iceland by the Northmen, which took place at the same time, this island becoming the far-flung bridgehead for their further wanderings along the coasts and seas from Newfoundland to Novaya Zemlya. Starting from Iceland, Eric the Red (Eirik Raude) set foot and settled on Greenland before the year 1000, and his son, Leif, on a return voyage from Norway discovered Vinland the Good (Vinland hit Góda), i. e. a stretch of the American continental coast, to which other stretches were added later. The motives and the routes of the Northmen varied; they followed no definite pathways; rather, they spread out into the wide area of the unknown, but they

were led, probably in part by currents, to and along the Arctic coasts.

It was only at the close of the Middle Ages that exploration developed into a world-moving idea, at first in the period of discovery with its goals of India and China—a new beginning by new peoples. On none of the medieval compass charts was Greenland to be found; the Dane, Claudius Clavus, on two maps of the first half of the fifteenth century, was the first to introduce to cartography the name of Greenland as well as the Norse conception of land connections in the north. There is nothing to show that Columbus or Cabot knew anything definite about their predecessors. It may be that Cabot was influenced by tradition and legend, as Bristol was in trade relations with Iceland during the whole of the fifteenth century. From Bristol the Venetian Giovanni Gabotto, known as John Cabot, fared forth in 1497 and reached Nova Scotia or Newfoundland as well as came into contact with the polar ice. But the spirit of maritime and colonial adventure had not yet been awakened in the English people. Portugal was the first to be active; after the establishment of the line of demarcation she wanted to see what there was still to be had in the north on her side of the boundary. The expedition sent out in 1500 under João Fernandez saw Greenland ("Terra Laboratoris"); the brothers Gaspar and Miguel Cortereal discovered Newfoundland in 1500–1502, and during the whole sixteenth century it was still counted a Portuguese possession.

When, after these and other more southerly discoveries, the New World began to take its place more and more as a barrier between Europe and coveted Asia, there arose the thought of circumnavigating the New as well as the Old World on their northern sides: "Northwest Passage" and "Northeast Passage" became the accepted slogans. The quest now clearly divided itself into two routes. England took over the leadership in both directions, brought forth a line of master discoverers, particularly in the northwestern field, and from this mighty school drew in part the force that led to her rise as the mistress of the seas. The first voyages were directed towards the northeast. The delineation of Asia on a map of that continent by Sigismund von Herberstein did much to evoke the hope that China could be reached by sailing along the Siberian coast. This circumstance and the founding of the Company of Merchant Adventurers advocated by Sebastian Cabot led to the voyages of Willoughby, Chancellor, and Burrough in the mid-sixteenth century and Pet and Jackman in 1580, with Novaya Zemlya and the Kara Sea as their objectives, and initiated commercial relations with Russia. The Dutch followed in the nineties with three expeditions on which, under the successful leadership of Barents and Heemskerk, Spitsbergen was discovered (1596).

Before the northeastern voyages slackened, the northwestern ones started in full swing. Martin Frobisher led the way with three voyages to Baffin Land in 1576–1578 and brought thence the iron ore of the northwest as a new attraction. There followed in 1585–1587 three voyages to Greenland, Baffin Island, and Baffin Bay by John Davis, whose reports led to the establishment there of the British whale fishery, thereby setting up a new practical allurement. The palm was achieved by Henry Hudson, who in four voyages in 1607–1611 took hold of the problem again at every point attacked by his predecessors and also attempted a direct advance by way of the pole. Near Spitsbergen he went beyond the eightieth parallel, in the northeast as far as the mouth of the Ob, and in the northwest to Hudson Bay, which he discovered and where, as a result of mutiny, he lost his life. Other voyagers followed in Hudson's wake, including the great Baffin, who with Bylot attained a latitude of 78° in Baffin Bay in 1616—a northing which was not exceeded till the nineteenth century—and who actually found the northern routes of access, Lancaster Sound and Jones Sound. Because of the ice, he was forced to the opinion that the route was not feasible, and thus for two centuries the Northwest Passage remained an unrealized dream.

Chronologically the Russians now take the leadership, their sphere of action being the northern part of the Asiatic continent. But let us first follow the threads on the American side, where attention was also first directed to the mainland. Here the fur trade called into being the Hudson's Bay Company in 1670. It sent out a number of expeditions, of which the most successful was that of the Scotsman Mackenzie, who in 1789 followed to its mouth the river that bears his name. Thus at the dawn of the nineteenth century exploration advanced from all sides towards the Arctic Archipelago. From this region it received a new impetus through John Barrow, who lifted it as no one had yet been able to do into the position of a British national task. W. E. Parry opened a breach in 1819 by his navigation of Lancaster Sound and his discovery of the islands in the heart of the archipelago that are named after him; John Franklin undertook land expeditions to the margins of the continent, on the most successful of which he surveyed a large stretch of the coast on both sides of the Mackenzie in 1825–1827, in coöperation with Back and Richardson; John Ross discovered Boothia Peninsula and the north magnetic pole and spent four winters in the ice (1829–1833); and the Hudson's Bay Company had a number of its employees fill in the last gaps of the continental shore.

After the end of a chapter in land exploration had thus been written in the forties, the ocean route which had been so brilliantly opened by Parry came again into the forefront of interest, with the project of forcing a way through the maze of already discovered straits

and islands to Bering Strait and at the same time of clarifying the map of the region. The fifty-nine-year-old Franklin, later to become famous, was despatched in 1845, with a large party experienced in polar matters, on the vessels *Erebus* and *Terror*, that had stood the test in the south—and never returned. This disaster instigated over forty expeditions, the Franklin search, which yielded a rich geographical harvest in the years from 1848 to 1879. Hardly any but Englishmen participated in the search; among them were many successful discoverers. Sledge journeys were developed on a large and admirable scale. On all three routes, from Baffin Bay, from Bering Strait, and overland from the Mackenzie, the advance began in 1848–1849. In the following year sixteen vessels entered the lists. Among others was McClure, who, proceeding from Bering Strait, discovered the Northwest Passage and Banks Island and followed up his discovery by returning to the Atlantic side, although, to be sure, on another vessel. There was Collinson also who, sailing along the continental shore for a long distance, prepared the passage where Amundsen succeeded in 1906. An American expedition equipped by Grinnell discovered Grinnell Land, the central section of Ellesmere Island. The Belcher expedition sent out in 1852 was forced to leave all its six vessels in the ice. But this expedition did more than all others in the Franklin search to clear up the situation as to the coasts and straits of the archipelago. Franklin had met his fate in the angle of the continent at King William Island, and here one of Rae's land expeditions came upon the first clues, which were later followed by further evidence of his tragic end.

After the close of the Franklin search no attack was made in this region until about the turn of the century, when Amundsen carried out accurate surveys and observations near the north magnetic pole in 1903–1906 and Sverdrup made important discoveries of land west of Ellesmere Island in 1898–1902. These discoveries in turn were continued from the Beaufort Sea side by Stefansson on his third expedition, in 1913–1918. This Arctic explorer, original in his methods, also made great inroads into the Beaufort Sea, which is difficult of access.

During the Franklin search Inglefield in 1852 determined that Smith Sound (up to then described as a bay) was a wide strait, which at that time happened to be open. Because of this, as well as the favorable ice conditions which had surprised others in the vicinity of Wellington Channel, there resulted the conception of an "open polar sea." This conception, the center of a violent controversy and finally proved to be incorrect, nevertheless continued to act as a magnet in drawing forth expeditions. Whereas previously the north pole had only occasionally been taken as a goal, as by Hudson in

1607 and by Parry in 1827, there now begins, by way of Smith Sound, the era proper of advance on the pole, predominantly an American era. The second Grinnell expedition under Kane in 1853–1856, although sent out mainly to search for Franklin, yielded to the spell of the open polar sea idea. His successors, Hayes (1860–1861), Hall (1871–1873), Nares (1875–1876), each advanced almost a degree of latitude farther north than his predecessor, the last to 83° 20′; but Nares, too, concluded "the north pole impracticable" and set up the conception of a paleocrystic sea, i. e. a sea always filled with old heavy ice masses, instead of an open sea, so that Petermann, who had strongly opposed the Smith Sound route and who had expected open sea rather in the European quarter, considered himself vindicated.

Thus the advances on the pole were interrupted. To be sure, in 1881 an American expedition under Greely again followed the same route and reached a greater northing, 83° 30′, but its task was strictly scientific observation at one of fifteen polar stations. It was Karl Weyprecht who energetically endeavored to turn polar exploration away from the mad rush to the pole, from exploits by individuals, and from the Passage quest, and to lead it into the path of systematic observations, to be taken simultaneously through a long period at a network of stations, for the solution of geophysical problems. His suggestion met with favor and resulted in the international polar year, 1882–1883, during which eleven nations coöperated in this way. Most of the members of Greely's expedition perished. For this reason it took a decade for Smith Sound to come back into favor again as the route to the pole. Then, in 1891, Peary began the series of expeditions that he carried on persistently for a quarter of a century along this route until his successful attainment of the north pole on April 6, 1909.

Whereas the western part of southern Greenland had already become known through the northwestern voyagers and, since the settling there of Hans Egede in 1721, had been studied rather closely and continuously, partly by native, partly by Danish and other investigators, the north and the east of Greenland still awaited exploration in the nineteenth century. In the north this exploration took place by way of the Smith Sound route through the expeditions already named, and recently especially through Rasmussen's expeditions and through Lauge Koch. In the east it began with the important voyages of the whalers Scoresby, father and son, in 1822; was considerably advanced by the two German expeditions, especially the second, which came into being in 1869–1870 thanks to Petermann's indefatigable activities and which discovered the vast Emperor

Francis Joseph Fiord; then was continued by Nathorst and others; and was finally completed, in its most difficult northeastern corner, by Mylius-Erichsen in 1906–1908 and his successors. The interior was explored only relatively late: the first crossing was carried out in 1888 by Nansen.

As in the northwestern Arctic Regions, so in the northeastern, we observe a differentiation in the methods as well as the motives of exploration setting in after the slogans of the Northeast and Northwest Passages had, at the beginning of the seventeenth century, lost their power of stimulation. The European Arctic islands were first visited and used as bases for fishing; the marginal zone of the continent profited by the urge to exploration awakened by the fur trade; the Arctic Sea in front of it called forth new attempts on the Northeast Passage; and attacks on the pole were made from here as well as from the advanced islands, especially from Franz Josef Land, which had been discovered last. Each archipelago and each part of the sea had its own problems, incentives, and methods; little by little scientific aims prevailed and finally became common to all.

Spitsbergen, ever since the attempt of the whalers in the seventeenth century and especially since the scientific exploration of the younger Scoresby and the investigations of the Swedish scientists Torell and A. E. Nordenskiöld, which began in the middle of the preceding century, has become the best-known polar land. In contrast to it Novaya Zemlya appears rather as a domain of the Russians—in the eighteenth century through its circumnavigation by the whaler Loshkin, in the nineteenth through the voyages of Lütke, Pakhtusov, von Baer, and others, to which names those of other investigators, especially Norwegians, were added, as indeed both nations are rivals here in their fishing interests. Different from Spitsbergen and Novaya Zemlya again, Franz Josef Land is one of the most recent discoveries, namely that of the Austrian expedition under Payer and Weyprecht in 1872–1874, which had the Northeast Passage as its objective. Repeatedly used since as a base for an advance on the pole, this land made possible Cagni's latitude record of 86° 34′ in 1900. Still later Emperor Nicholas II Land (now Northern Land) was discovered in 1913 entirely unexpectedly by Vilkitski, whereas the New Siberian Islands, whose existence had been rumored since the middle of the seventeenth century and established by the visit of the Russian trader Lyakhov in 1770, were only disclosed to science by Bunge and von Toll in the eighties of the nineteenth century.

In the Asiatic sector the emphasis, however, lies on the continental coast. Here polar exploration is synonymous with the exploration of northern Siberia. The conquest of Siberia, which began as early

as 1578 by the Cossack leader Yermak and then continued under the aegis of the fur trade, brought daring Cossack leaders down the streams to the coast of the Arctic Sea in the seventeenth century. One of them, Semen Dezhnev, starting from the Kolyma, circumnavigated the Chukchi Peninsula in 1648. This discovery remained unknown and was repeated in 1728 by Vitus Bering. The real scientific work and the complete survey of the coast, particularly of its middle section, were carried out by the Great Northern Expedition of 1734–1743, in which eminent scientists of different nations, including German, participated. The interior of the Taimyr Peninsula was first accurately revealed in 1843 by the voyage of Middendorff.

Although James Cook, who had reached Bering Strait in 1778, declared the Northeast Passage to be entirely impossible, Russia in the nineteenth century continued voyages to the Siberian coast with other objectives in view (furs) and partly also with the outspoken intention of carrying out the Northeast Passage. Such important names as Krusenstern, Kotzebue, Wrangel, Anjou are connected with these endeavors during the first quarter of the nineteenth century. In its last quarter the trade relations that had been established with the West Siberian rivers awakened in Nordenskiöld the plan of the Northeast Passage, which he actually carried out in the *Vega* in 1878–1879.

The Siberian seas, finally, have been used as a base for an advance on the pole and for the hydrographic and meteorological exploration of the Arctic Sea. The first undertaking of this kind immediately followed Nordenskiöld's voyage. When no news came of the wintering of the Swedish scientist, James Gordon Bennett, Jr., of New York, sent out the *Jeannette* under De Long to look for him. At Bering Strait De Long heard that Nordenskiöld had left; he himself then undertook an advance on the pole, during which the vessel with the greater part of the crew and its brave leader was lost. Fragments of the *Jeannette* came ashore in southern Greenland and awakened in Nansen the ingenious plan of crossing the Arctic Sea in the same way by drifting with the ice. He carried out this plan in 1893–1896 by letting the *Fram* become frozen in the ice at the New Siberian Islands. The ship drifted in a varying course towards Spitsbergen; Nansen left her in latitude 84° for an advance on the pole in sledges and later reached Franz Josef Land. This undertaking not only resulted in the latitude record of 86° 4′ but constituted the first thorough investigation of the Arctic Sea and opened up remarkable vistas in this field of knowledge. To the same period belongs the first attempt to explore the Arctic by air, namely that made by Andrée in 1897 in a non-dirigible balloon, utilizing Danes Island in northwestern Spitsbergen as a starting point, an attempt from which he never returned.

TABLE SHOWING, BY ROUTES OF ACCESS, THE HIGHEST ARCTIC

Year	American Arctic Archipelago	Baffin Bay, Smith Sound	East Greenland	Spitsbergen
1587	...	73° (58° W.) Davis	...	...
1607	...	...	73½° (20⅓° W.) Hudson	81° (20° E.) Hudson
1616	...	78° (70° W.) Baffin	...	...
1770	...	...	...	...
1773	...	...	...	80° 48′ (20° E.) Phipps
1821	...	...	...	...
1822	...	...	74° 20′ (20° W.) Scoresby, Jr.	...
1823	...	...	74° 50′ (18° W.) Clavering	...
1827	...	...	...	82° 45′ (20° E.) Parry
1849	...	...	...	...
1850	75° 25′ (95° W.) De Haven	...	...	...
1851	76½° (93° W.) Penny	...	...	...
1852	...	78° 28′ (75° W.) Inglefield	...	...
1853	77° 45′ (116° W.) M'Clintock	80° 40′ (66° W.) Morton (Kane)	...	...
1854	...	...	...	...
1861	...	81° 35′ (70° W.) Hayes	...	...
1870	...	...	77° 2′ (19° W.) Koldewey	...
1871	...	82° 26′ (61° W.) Hall	...	...
1874	...	...	...	...
1876	...	83° 20′ (61° W.) Markham (Nares)	...	...
1881	...	...	...	...
1882	...	83° 30½′ (41° W.) Lockwood (Greely)	...	...
1895	...	...	...	...
1900	...	83° 50′ (34° W.) Peary	...	...
1901	...	...	...	...
1902	81° 38′ (92° W.) Sverdrup	84° 17′ (65° W.) Peary	...	...
1905	...	...	78° 17′ (19° W.) Duke of Orleans	...
1906	...	87° 6′ (40° W.) Peary	...	...
1907	...	...	83° 30′ (26° W.) Koch (Mylius-Erichsen)	...
1909	...	90° (70° W.) Peary	...	...
1913	...	...	...	...
1914	82½° (105° W.) MacMillan	...	...	...
1917	80° 30′ (113° W.) Stefansson	...	...	...
1918	...	...	...	...
1925	...	...	...	87° 43′ (10° 37′ W.) Amundsen, Ellsworth
1926	...	...	...	90° (11° E.) Byrd
1926	...	...	...	90° (11° E.) Amundsen, Ellsworth, Nobile
1927	...	...	...	...

LATITUDES REACHED (Longitudes in parenthesis)

Franz Josef Land	New Siberian Islands, Taimyr Peninsula	Eastern Siberia, Bering Strait, Beaufort Sea	Highest Latitude to Date: Lat.	Highest Latitude to Date: Year
			73°	1587
			81°	1607
		72° 38′ (165° E.) Leontev		
	76° 33′ (138° E.) Anjou			
			82° 45′	1827
		71° 18′ (175° W.) Kellett		
		73° 23′ (164° W.) Collinson		
78° 49′ (42° E.) Weyprecht				
82° 5′ (58° E.) Payer				
			83° 20′	1876
	77° 43′ (151° E.) DeLong			
			83° 30½′	1882
86° 4′ (95° E.) Nansen			86° 4′	1895
86° 34′ (68° E.) Cagni			86° 34′	1900
	78° 32′ (142° E.) von Toll			
			87° 6′	1906
		72° 3′ (150° W.) Mikkelsen		
			90°	1909
	81° (98° E.) Vilkitski			
		74° (151° W.) Storkerson		
			90°	1926
			90°	1926
		77° 45′ (175° W.) Wilkins		

In 1918 Amundsen began with the *Maud* his advance in the Siberian coastal region and after three winters reached the Pacific Ocean by the Northeast Passage. The present development of aviation has led to a number of recent flights in the Arctic. By airplane from Spitsbergen Amundsen and Ellsworth in 1925 flew north to 87° 43′ and Byrd to the north pole in 1926. In that year Amundsen, Ellsworth, and Nobile flew across the Arctic Sea from Spitsbergen via the pole to Alaska in a dirigible airship. From Point Barrow, Alaska, Wilkins in 1927 flew by airplane northwest a distance of about 850 kilometers.

If the most recent activities in both halves of the Arctic are reviewed, there results the impression of a decided increase in intensity since the nineties, especially if, in addition to major attempts, which alone it was the intention to bring out in the preceding survey, the other enterprises that have been undertaken—still to be discussed under the individual regional sections—are taken into consideration. In the forefront of all of these stand scientific aims, pursued in many ways and thoroughly on land, sea, and inland ice. But almost all the incentives of the preceding periods are also involved, namely fisheries (in Alaska as well as in Barents Sea), mineral resources (in Alaska, Spitsbergen, Novaya Zemlya), trade routes (to the Yenisei, to Hudson Bay), and not the least the Passages themselves (Amundsen in the northwest and Brusilov in the northeast) and the pole (Nansen, Andrée, Peary, Amundsen). And what is most surprising is that all, including the great sporting endeavors, led to the goal in a short time. Thus, scientific investigation of all kinds, from terrestrial magnetism and deep-sea exploration to archeology and linguistics; advances on all routes, not only the old tested ones but also such difficult ones as Beaufort Sea and northeastern Greenland; the employment of all known methods and means; and finally results that fulfill the dreams of centuries—all of these together are characteristic of the polar exploration of our days. In the last analysis this totality of success is based on the summation of experiences and the increase and perfection of technical means.

At first exploration was limited to summer voyages. The first involuntary wintering, which took place at the most favorable spot, namely Kola Peninsula (Willoughby, 1553–1554), ended with the death of all sixty-two participants; and the first intentional wintering, that of Barents in 1596–1597 on the northeast coast of Novaya Zemlya, was characterized by great suffering from cold and scurvy as well as the death of the gallant leader and a number of the party. At Spitsbergen, too, at the time of the great whale fishery, the winter was considered the gravest of terrors, and the first involuntary wintering there by the English is vividly described in a book whose title begins with the sentence: "God's power and providence, shewed

in the miraculous preservation and deliverance of eight Englishmen left by mischance in Greenlan anno 1630 nine moneths and twelve days" (Spitsbergen at that time was still called Greenland). Hudson, during his wintering in Hudson Bay in 1611, fell a victim to his discontented crew. From winterings in the same region Munk returned in 1620 with only two companions, James in 1632 with less loss but in a pitiable condition. As early as the eighteenth century vessels wintered in Hudson Bay without difficulty, but only since the resumption of the Northwest Passage voyages at the beginning of the nineteenth century did wintering on vessels as well as on land become customary and safe: John Ross spent four winters in the ice in 1829–1833, an achievement outdone only in 1913–1918 by Stefansson.

The great sea expeditions were at first limited in their discoveries by the advance made in their ships. These were sailing ships; they were replaced by steam for the first time on Ross's four-year voyage (by the *Victory*). The land expeditions brought exploration by canoe to an especially high state of development on the American mainland, which abounds in rivers and lakes, and also extended this method to the coast, along which, for example, the fur traders Simpson and Dease in 1837–1839 carried out one of the longest Arctic boat voyages for a distance of 2400 kilometers. Finally sledges also came into use as a supplementary means of transportation on the sea expeditions, a vehicle that had been utilized on the Asiatic polar coast throughout the eighteenth century on exploring expeditions, particularly on those of the Great Northern Expedition. On his advance from northern Spitsbergen in 1827 Parry for the first time carried out the idea previously expressed by Scoresby of advancing on the pole by sledges; his vehicles could be used as boats as well as sledges. A more extended use of this new means of exploration was immediately made by the great Ross expedition in its exploration of the Boothia Peninsula. The sledge method came into full fruition during the Franklin search in the maze of islands along the coast; M'Clintock covered over 1400 kilometers in sledges as early as 1851, and the longest sledge journey was that of Schwatka's in 1878, which covered 5200 kilometers in eleven months. In the Asiatic sector similar sledge journeys had already been accomplished, e. g. by Baron Wrangel in 1822 for a distance of 2400 kilometers in 78 days.

Various kinds of hauling power for the sledges were tried—men, dogs, reindeer, ponies. Ponies were especially valuable on Koch and Wegener's crossing of Greenland. Nordenskiöld in 1872 for a sledge advance on the pole from Spitsbergen took with him forty reindeer; however, they ran away. They have also been used as pack animals recently, for instance in 1908 on a Russian expedition on the Samoyed Peninsula and again in 1909 on another expedition in the polar Urals, when as many as 1500 were employed. During

the Franklin search it was the practice to use man power for hauling the sledges, and Nansen also used the same means when he crossed Greenland on snowshoes, introducing therewith a new means of locomotion. The use of the automobile has also been attempted, but so far only to a small extent, the snow motor being the latest development. At present the dog sledge is the method that is by far the most common. On many of the largest expeditions, especially in the advance on the pole, the last ounce of power of the last dogs was hardly less decisive than the endurance and will power of the men. In the tundra the reindeer is to be preferred, as it can find its own nourishment there. On the ice the dog retains first place: he is easily fed, is thoroughly hardened to the weather, and because of his small size is readily adaptable to difficult ice formations.

The general question whether traveling about or making observations from fixed stations is the more profitable method of polar exploration cannot be decided on principle. It is not a question of using one method to the exclusion of the other but rather of combining them both effectively and of continually adjusting to the given conditions. Every advance and every movable observatory, in general, endeavors to have a fixed base for comparison, and in a number of cases expeditions have established a secondary station in addition to their main station. Permanent polar stations also have already been established in Greenland, Jan Mayen, and Spitsbergen.

For an advance into the great unknown areas of the north all three media—air, water, ice—have now come into use. The airship had already been tried out before the war, the airplane recently in Spitsbergen, and both had in general demonstrated their availability for polar exploration. The first major success was Amundsen and Ellsworth's flight towards the pole in 1925, followed by Byrd from Spitsbergen to the pole and back and in turn by Amundsen, Ellsworth, and Nobile in the transpolar flight of the airship *Norge* in 1926. Water affords vessels the opportunity, as before, to penetrate without hindrance through the ice to certain limits. They can then make further advances either in conflict or in alliance with the ice. The former is the method of the ice-breaker, whose introduction into polar exploration is to the credit of the Russians; the latter is the method of drifting with the ice when it is moved by current and wind, as on the voyage of the *Fram*. This was an undertaking that had remained unique until it was recently tried again by the *Maud*, but unsuccessfully. At all events, the ship has the advantage of providing comfortable conditions and liberating the largest number of persons for purely exploratory work and, in addition, of carrying with it an extended equipment—a floating observatory. Finally, as to the third medium, the ice, dog sledges have made it possible to cross this frozen cover of the sea for long distances; and this method also im-

mediately divides itself into two others which are fundamentally different and which may be characterized, from their special exponents, as the Peary method and the Stefansson method. For twenty years Peary accumulated experience about living and traveling on the ice and trained for his purpose the northernmost human beings, the Etah Eskimos; that is, he organized the members of the human race that by nature are best fitted for a march on the pole and imbued them with his energy and strength of will. With 23 men, 133 dogs, and 19 sledges he started on his march, divided into advance, support, and rear guards, each of which sections functioned separately and all of which worked together like clockwork, with a view to preserving for him as the soul of the whole undertaking the utmost strength for the final dash—a plan that was at once a model in mathematical calculation and a work of art. Stefansson's method, too, is based on a multitude of experiences and on subtle observation of the Eskimos and polar nature. But he does not utilize and organize the Eskimos; he becomes an Eskimo himself and achieves good results by this method, whereas his third expedition, begun with a large party and requiring organization, was in constant trouble despite his personal achievements. His "living off the country" is the Eskimo method first used by Hall in the sixties and used as well by other Americans and by Danes (Schwatka, Rasmussen). However, he extends it to the open sea, rejecting the theory that the sea below the ice is devoid of life. Peary raced with hunger through the desert; Stefansson made himself at home on the sea ice. The former method requires a large equipment in men and supplies; the latter excludes it. The exploring possibilities of the former are limited by its haste, of the latter by its small equipment. But common to both methods is the fact that except for the period of greatest darkness both methods make the most of the winter, the terror of former polar expeditions, because during that season travel is safest.

Position, Structure, and Articulation

The Arctic Regions abut on a number of old land cores, the Siberian, Baltic, and Hudsonian (Fig. 1). Between them, as well as to the north of them, mountain and continent building forces have created land masses. Thus horizontal Paleozoic and Mesozoic strata of the Arctic Archipelago overlap the northern margin of the Canadian Shield. The Caledonian mountain axis of Norway is continued by way of Bear Island and West Spitsbergen to northern Greenland (Fig. 2). The outermost remnants of the Russian tableland lie beyond Barents Sea and are represented by eastern Spitsbergen and Franz Josef Land, which are in part covered with basalt but have been little folded. The old folds of the Urals, or rather of one of their lateral branches,

continue as a narrow and long backbone by way of Vaigach to Novaya Zemlya. North of the Siberian continental core first appear the sediments of Paleozoic and then, along the Arctic fringe, of Mesozoic and later transgressions; and the Siberian island groups also appear to be intercalated in the extended structural lines of the mainland mass. Thus the Arctic region is anchored in many places to the cores, tablelands, and mountain axes of the two major mainland areas of the present. It forms a girdle of peninsulas and islands around a

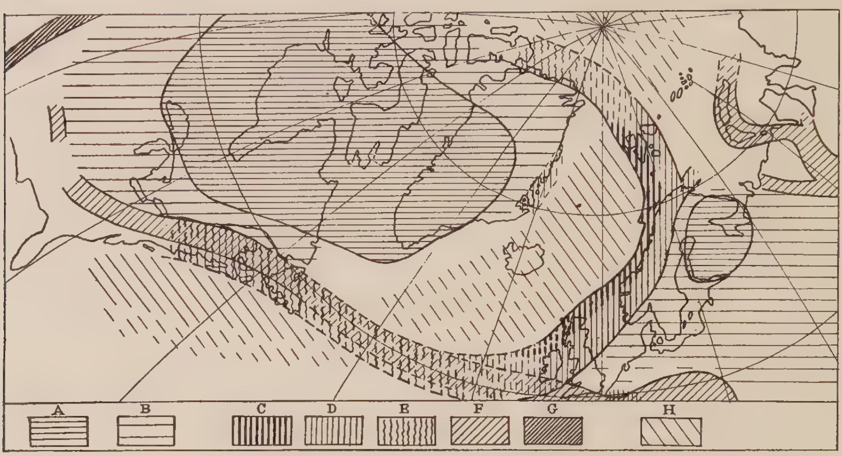


FIG. 1—The relation of the structural elements of eastern North America and northwestern Europe to those of the Arctic Regions. Scale, 1:90,000,000. A and B, the stable areas; C-G, the zones of folding; H, areas of greatest vertical movement. Specifically: under A, the Baltic and Canadian Shields; under B, the Russian tableland; under C and D, the Caledonian folding; and under F, the Ural-Vaigach-Novaya Zemlya and Ozark-Appalachian belts. (From Holtedahl, *Amer. Journ. of Sci.*, 4th Ser., Vol. 49, 1920, p. 18, Fig. 12.)

large sunken area north of these continental cores. At numerous places in the marginal areas basalts occur, as in West and East Greenland, Jan Mayen, Iceland, Spitsbergen, Franz Josef Land, on Bennett Island, and in Bering Sea.

To the sea basin, on the other hand, are appended no less variegated members which project into the mainland. On the American side Beaufort Sea is adjoined by the maze of ramifying straits that traverse the tableland of the Archipelago. The mediterranean sea of Hudson Bay, an epicontinental sea on the Canadian Shield, is connected with the network of straits through Fury and Hecla Strait as if by a thread, whereas Lancaster, Jones, and Smith Sounds lead into the wide, deep fault trough of Baffin Bay and Davis Strait. Surrounded by these arms of the sea lie the two large projections of the mainland, the Barren Grounds and Labrador peninsulas; and, in addition, as their connecting link, Baffin Island; beyond lies the rest of the Arctic Archipelago and, farther to one side, Greenland. On

the Asiatic side shallow marginal seas cover the continental shelf between the edge of the deep-sea basin and the coast of the mainland: Barents Sea, Kara Sea and its continuation to Northern Land which may be designated the Taimyr Sea,[1] Nordenskiöld Sea, and the East Siberian Shelf Sea from the De Long Islands to Point Barrow. All these parts of the sea, as well as the land members, are completely Arctic in character. The larger land areas which are segregated by them are Spitsbergen, Franz Josef Land, Novaya Zemlya with Vaigach, the Taimyr Peninsula and Northern Land, and finally the New Siberian Islands. A number of small remnants lie off by themselves, among them Wrangel Island, Bear Island, and Jan Mayen.

Thus the Arctic Regions consist of a central sea basin and a peripheral belt of lands and seas resulting from the close interlocking of the basin with the two continents. The lands within this belt, i. e. the belt of lands of Arctic character, attain their greatest width in two places on the eastern side of North America, one along the 60th meridian, where they extend through 28 degrees of latitude, or 3100 kilometers, from the corner of Grant Land to Hamilton Inlet in Labrador, and the other along the major axis of Greenland, a distance of 2600 kilometers through continuous land.

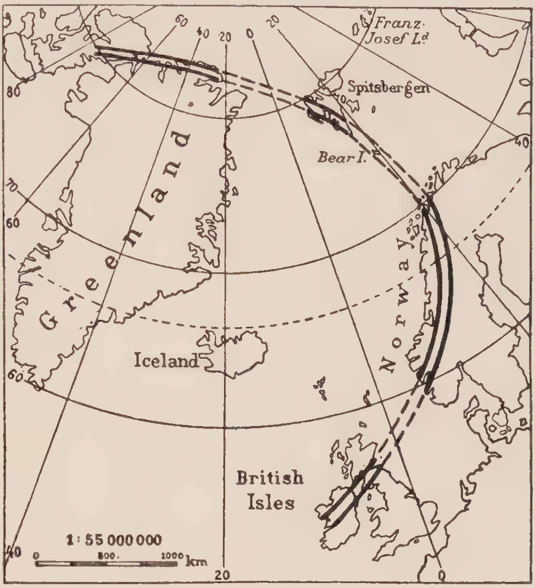


FIG. 2—The Caledonian folding.

The enclosure of the Arctic Regions by the two oceans is simpler than by the continents. Toward the Pacific side Bering Strait, only 92 kilometers wide, interrupts an internal land connection and leads into Bering Sea; on the Atlantic side a wide gateway between Greenland and Spitsbergen leads into the North European Sea over a ridge rising to within 1000 meters of the surface. In both cases between the central basin and the ocean lies a vestibule which connects with the main body of the ocean only across an island series,

[1] Present Russian usage applies the name Kara Sea to the whole extent from Novaya Zemlya to Northern Land.—EDIT. NOTE.

the Aleutians, on the one side, and across a ridge, the Iceland-Faeroe Ridge, on the other. Both vestibules are temperately polar, or partially polar, in character; the North European Sea exhibits a particularly sharp contrast between its highly Arctic western and its non-Arctic eastern side, whereas in Bering Sea this contrast is only slightly evident.

In these conditions of position and articulation lies one of the difficulties of delimiting the region on sea and land. To be sure, frost is the leading characteristic in both, as expressed respectively in drift ice and frozen ground. But in detail this limit frequently fails; for the immense forests and even the grainfields of Siberia stand in large part on frozen ground, and the limit of drift ice still encloses all of Newfoundland. Therefore the mean annual isotherm of 0° C., which almost coincides with the limit of frozen ground, is also an unsatisfactory criterion. The 10° July isotherm offers a better limit; it coincides surprisingly well with the boundary between forest and tundra, i. e. a marginal belt which is the basis of a fundamental change in the aspect of the landscape as well as in animal life and human economy.

The only remaining difficulty, then, is the inclusion of transitional Iceland. Hettner refers the island to the Polar Regions, Philippson to Europe. It is bathed more by the Gulf Stream than by polar waters and lies almost entirely south of the 10° July isotherm. The temperature of the coldest month on the south coast is not lower than in the region of the lower Rhine. The number of flowering plants far exceeds that of all other polar lands of similar size. Above all, the island is neither devoid of settlements nor is it inhabited by the indigenous population; on the contrary, it is European in race, economy, and civilization. Therefore we exclude it from the Arctic Regions as here considered.

The Siberian Arctic fringe was in the main disclosed by the Russians, the American fringe by the British and the Americans. At Bering Sea both groups met. About the three Atlantic entrances, however, Baffin Bay, the North European Sea, and Barents Sea, many maritime nations have in competition acquired explorers' fame. These features of the history of discovery are due to the position and articulation of the region as well as to the period of time at which each maritime nation entered the arena. The smaller northern coastal peoples have in no small measure also participated in the more substantial aspects of exploration. But other European cultural nations, Germany, Austria-Hungary, Italy, France, Belgium, and even Switzerland, have likewise taken part through special investigations by their nationals.

Landforms and Surface Cover

As to landforms, lowlands and plateaus (the latter partly level, partly undulating) dominate throughout. Mountain ranges in the proper sense of the term are of secondary importance and are restricted to the marginal zones: West Spitsbergen, western and eastern Greenland, eastern Labrador, eastern Baffin Island. The level forms are partly of tabular structure, partly recent marine abrasional surfaces, and partly they are due to other eroding agencies, especially ice. Sedimentary tablelands and volcanic sheets are mainly responsible for the appearance of the landscape in the American Archipelago, in eastern Spitsbergen, and in Franz Josef Land. Recent areas of uplift constitute more or less wide margins in Siberia and also in many other areas, for instance in Spitsbergen. Traces of Quaternary uplift in the form of terraces are to be found quite commonly in the Arctic, and their clean-cut development may be due to the powerful action of frost and ice at sea level along the coasts. On the eastern coast of Labrador the terraces are as high as 100 meters; in Baffin Island and Ellesmere Island, 150–200 meters; in Spitsbergen, 130 meters; in northern Greenland, 500 meters. The ice has also left undulating rock lowlands or rock plateaus where it has disappeared, e. g. in the peninsula of the Barren Grounds, and, where it still exists, itself displays a similar surface form when its area is extensive.

As to surface cover, three main types of landscape may be distinguished: rock desert, ice desert, and tundra. The rock desert is diversified both by many interspersed lakes and by larger and smaller patches of vegetation on slopes and lowlands. In contrast the tundra and the inland ice constitute two landscapes of extreme uniformity and occupy the largest areas of the Arctic. To be sure, both have their detailed forms and phenomena which impart interest and variety. The inland ice has undulations and fissures; the tundra in its summer garb of delicate plants in places resembles flower beds and is the delight of the botanist. But the landscape, viewed as a whole, is the quintessence of monotony in form and color—inland ice as well as tundra. The tundra occupies a wide belt chiefly on the margins of the continents; the inland ice has its main development in Greenland, compared with which all other ice caps are insignificant in size. At all events, the ice sheets are located about the Atlantic breach in the land circle, as this is the area which, with the barometric depressions of Davis Strait and Iceland, furnishes the sustaining source of precipitation. In the continental interiors, by contrast, a hot summer melts away the sparser snow even in the higher latitudes. The tundra develops small-scale forms as a result of freezing and thawing: networks of polygonal cracks, stone circles about upraised clay areas, long solifluctional strips, etc., likewise such plant formations as tussocks, moors, and similar phenomena.

Relief is imparted to the surface of the ice not so much by the underlying terrain as by cracks and cryoconite holes in the marginal zones. These have been described mainly from Greenland and Spitsbergen. The dust that lies in these holes adds to the ablational effect, and, as they occur only in marginal zones, ablation is here much stronger than in the interior. The ice melts mainly in this indirect manner and not through the warmth of the air, as in lower latitudes. For that reason also its margin does not end in flat tongues but generally in steep walls, "Chinese walls," as in Spitsbergen, Greenland (Fig. 79), and Grinnell Land.

A third type of relatively uniform surface cover might be added to the types of inland ice and tundra already described: the ice surface of the sea when it attains its fullest development, as in the central Arctic Basin.

In spite of the uniformity of these widespread major types, the Arctic presents scenes of variety, form, and life, especially along its margins, with their coastal mountains, rock walls, glaciers, straits and bays, floes, and castles of floating ice. These landscape features, through the intimate dovetailing of water and land, play an important rôle in Arctic nature: the coastal regions are here of greater consequence than in other parts of the world.

Climate

Its intermediate position between two continents and oceans brings the Arctic region under the influence of two high-pressure and two low-pressure areas. The lows lie near Iceland and the Aleutians, the highs in Siberia and North America. That is the mean annual situation; in winter it becomes intensified and therefore dominates through the larger part of the year. The high-pressure areas are connected over the ice-covered Arctic Basin by a saddle which thus separates the low-pressure areas and has been called by Supan the "Arctic wind divide." On the Atlantic side of this high-pressure ridge the *Fram* drifted past the New Siberian Islands. Depressions therefore hardly reach the north pole and rarely go beyond latitude 80°. On the whole of the *Fram* route there were no storms; Peary, to be sure, experienced high wind velocities even in high latitudes. In winter (Fig. 3) poles of cold lie on the axis of the high-pressure saddle, i. e. in eastern Siberia, in the American Archipelago, in Greenland, and at the north pole, whereas from the opposite Bering Sea and North European Sea sides the isotherms bend inwards toward higher latitudes and in the North European Sea especially an intensive positive anomaly is developed over a wide area because of the Gulf Stream. At the cold poles temperatures of nearly –60° C., at the Siberian even of –68°, have been observed. In summer (Fig. 4) only

the cold poles over Greenland's inland ice and over the ice at the north pole maintain themselves. Thus the north pole remains an extreme in summer as well as in winter and theoretically should have a mean annual temperature of –22.7° C.—the lowest in the Arctic. On the other hand, Siberia and North America exceed it in annual range (Siberia, 65°) as a result of their considerable summer heat. This last circumstance is illustrated by the temperature of the water in a small shallow lake near Verkhoyansk, which averages more than 20° on some days, although the lake is ice-free only three to three and a half months during the year.

The region of coldest winter (Siberia) thus falls outside of the Arctic and is associated with a hot summer; by contrast the typical polar climate is a combination of a cool summer with a winter which is still cold. The July mean on the route of the *Fram* was just 0°; that of Jan Mayen, northeastern Greenland, northwestern Spitsbergen, the mouth of the Lena, northern Alaska, and the Gulf of Boothia lies between 3° and 5°. Thus large areas coincide in having a cool summer, whereas the distribution of cold winters varies greatly as to region. The winter cold is also often interrupted by warmer weather. The winter is changeable, the cool summer on the other hand uniform. Furthermore, the abrupt change to summer and its short duration are characteristic throughout. The longest period of daylight in the latitude of Disko Island lasts 65 days, in northern Spitsbergen 135 days. As soon as it is at an end night frosts slowly set in and winter draws near gradually, interrupted by warmer weather up to the darkest period. There is then a long lag in the incidence of the lowest monthly mean, which sets in as late as February or March or even April. At that time, however, the sun is continually going higher, and the constant sunshine exercises a thawing action even when the air temperature is far below the freezing point; it continues to increase rapidly in strength and as early as July brings about the maximum of warmth. Hence autumn is a quiet dying away of nature, spring a sudden awakening. "In eight days the whole change may have taken place," says Andersson. "The snow has melted, and everywhere buds and green leaves appear where only a week before the dun hues of winter predominated." Geese appear along the thawing brooks, and soon other birds follow.

As a result of the close proximity of water and ice the summer brings much fog. In the coastal belt the scene may change abruptly: behind thick walls of fog high masses of piled-up ice may suddenly appear, then again in clear air a vista of open lanes or of jagged rock walls and glacier masses is disclosed to the explorer. Deception as to distance is great; mountains are taken for ice hills, walrus tusks for glaciers; and many an Arctic report of land has proved to be false. The fog may last for days and become especially depressing to the oc-

cupants of a vessel subjected to the whims of the ice. "Ugh! that endless, stubborn fog of the Arctic Sea! When it lowers its curtain, and shuts out the blue above and the blue below, and everything becomes a damp gray mist, day in and day out, then all the vigor and elasticity of the soul is needed to save one from being stifled in its clammy embrace. Fog, and nothing but fog, wherever we turn our eyes. It condenses on the rigging and drips down on every tiniest spot on deck. It lodges on your clothes, and finally wets you through and through. It settles down on the mind and spirits, and everything becomes one uniform gray" (Nansen).

FIG. 3—Mean January isotherms in the Arctic (in degrees C.). Scale, 1:100,000,000.

The winter is dry and clear. Any light wind immediately causes the sandlike snow to drift. The moisture content of the air is so slight that only minute crystals form in it with a crackling sound, and the slightest sounds are audible at remarkable distances. The clearness of the air in turn fosters radiation to such a degree that the clear winter days are far colder than those that are overcast. Temperature inversion also becomes a permanent phenomenon and may amount to several degrees at so low a height as 30 meters.

Precipitation in the whole Arctic region is slight, generally less than 200 millimeters a year and in places hardly 100 millimeters. The great dryness and cold during the longest part of the year have a potent conserving effect. The Eskimos make use of this in gathering their meat supplies. Depots of previous expeditions have been eaten decades later. Driftwood high above the present beach looks as if it had just drifted in. The dryness creates a torturing thirst among Europeans. The air is almost wholly free of bacilli; respiratory diseases are rare, although the change in temperature on leaving or entering a dwelling may often amount to 50° or 60° C. Vital energy is also augmented. This is diminished, however, by the lack of light, which creates depressional and apathetic conditions, but only in the case of Europeans; the Eskimo is psychically adjusted to this condition, and it is precisely in the dark period that he has his happiest celebra-

tions, as at that time he cannot go hunting so much and lives on his provisions. The cold can be supported relatively well because it is associated with dryness and calm. It is easier to support than the radiation and warmth of summer, which is accompanied by greater humidity and by the torment of mosquitoes and which creates the sensation of a tropical climate when the temperature is only 5° C.

FIG. 4—Mean July isotherms in the Arctic (in degrees C.). Scale, 1 : 100,000,000.

Finally a word should be said about the colors and moods that may overspread this hoary realm of frost, and not least in the marginal zone; for in the lower latitudes, especially of North America, the aurora borealis attains its maximum brilliance and frequency, and the midnight sun also, in its soft twilight glow, creates miracles of color. Even the Arctic night has its own majestic beauty. "It is dreamland, painted in the imagination's most delicate tints; it is color etherealized. One shade melts into the other, so that you cannot tell where one ends and the other begins, and yet they are all there. No forms—it is all faint, dreamy color music, a far-away, long-drawn-out melody on muted strings. Is not all life's beauty high, and delicate, and pure like this night? Give it brighter colors, and it is no longer so beautiful. The sky is like an enormous cupola, blue at the zenith, shading down into green, and then into lilac and violet at the edges. Over the ice-fields there are cold violet-blue shadows, with lighter pink tints where a ridge here and there catches the last reflection of the vanished day. Up in the blue of the cupola shine the stars, speaking peace, as they always do, those unchanging friends. In the south stands a large red-yellow moon, encircled by a yellow ring and light golden clouds floating on the blue background. Presently the aurora borealis shakes over the vault of heaven its veil of glittering silver—changing now to yellow, now to green, now to red. It spreads, it contracts again, in restless change; next it breaks into waving, many-folded bands of shining silver, over which shoot billows of glittering rays, and then the glory vanishes. Presently it shimmers in tongues of flame over the very zenith, and then again

it shoots a bright ray right up from the horizon, until the whole melts away in the moonlight, and it is as though one heard the sigh of a departing spirit. Here and there are left a few waving streamers of light, vague as a foreboding—they are the dust from the aurora's glittering cloak. But now it is growing again; new lightnings shoot up, and the endless game begins afresh. And all the time this utter stillness, impressive as the symphony of infinitude" (Nansen).

Plant Cover

Arctic lands even in the highest latitudes that have been visited are not wholly devoid of plant life. Vegetation, to be sure, is subjected to severe conditions that impart special characteristics; these are the dry, short, and cool summers and the thinness of the soil that covers the frozen ground, smooth rock, or débris of mechanical denudation, as the case may be. The plant gets least of its moisture from precipitation, which is not even at its maximum in summer; rather, it receives the greater part of it from the snow melting on the slopes, from the thawing ground, and from the coastal fogs, which, especially for lichens and mosses, are an important form of humidity and at the same time a protection against evaporation and loss of heat. As a result of the small amount of moisture plant life is developed in xerophytic forms: it is characterized by small leather-like leaves, a tendency to succulence, hairlike coverings, tussock formation, low stature, often very short stems. Bushes and even grasses often grow one-sided, as the windward side dries up. Much-exposed surfaces carry only lichen coverings. As a result of the shortness of the summer, which in some places lasts only two months, most plants are perennial, putting on leaves and buds in the autumn and blossoming forth rapidly in the following June to enliven the browns, greens, and whites of the landscape with their variegated colors. Often parts that have died, as they do not easily decompose, remain standing for several years in juxtaposition to freshly developed growths and thus increase the general appearance of aridity.

Of advantage to the vegetation in its short growth period are the steadiness of the summer temperature, the constancy of radiation, and, above all, the indirect effect of radiation from the ground. The temperature of the ground may be considerably higher than that of the air; in northeastern Greenland, with a July mean of 4.4° C., the ground temperature was found to be as much as 6° higher at a depth of 4 centimeters, that of the air between plant parts even 8½° higher. For this reason tall trees are lacking, because they require a July mean of 10°, but their dwarf representatives are abundant, as they find the necessary warmth near the ground. With their branches they clasp the warmth-giving rocks and are intertwined with the

moss pads in an inextricable network. A tree trunk may be meters long, but it lies prone on the ground. Likewise the roots seek to spread out widely in the thin layer of soil over the frozen ground. Thus even in the north of Greenland there are dwarf willows and birches.

The dominant character over large areas is imparted, however, by carpets of moss and lichen, known in Siberia as tundra and in America as barren grounds; grasslands, however, also exist to an extent that led to the coining of the expression "Arctic prairies." They are densest in the marginal areas, principally on the Aleutian Islands and in southwestern Greenland, also on Iceland, the Faeroes, and other lands which lie outside of the Polar Regions. Taken as a unit they are called by Passarge "subpolar meadows" and by him are differentiated from the polar tundra. Where the Arctic vegetational cover becomes discontinuous an important determining factor, in addition to soil type and humidity, is the shape of the surface, effective through insolation: northern slopes are relatively barren, whereas there is always growth and flowering on the slopes that face the south.

The general characteristic is, of course, the dearth of species. Southwestern Greenland is at the upper end of the scale with nearly 300 flowering plants. Spitsbergen has only 125 of them; throughout the whole extent of the Siberian tundra the number of plant species hardly exceeds 350. The flora is quite circumpolar. Many species occur again and again, such as the willows (*Salix polaris*), the reed and wool grasses, the *Polytrichum* and *Sphagnum* mosses, the heath plants of the Rhododendron and Cassiope families, *Potentilla* and *Pyrola*, many saxifrages and whitlow grasses (*Draba*), the berry species *Vaccinium uliginosum* and *Empetrum nigrum*, and furthermore many plants known in lower latitudes, such as heather, poppy, and arnica. In places there are whole flower beds, i. e. bloom-mats, all aglow with large colored flowers. There are few endemic forms in the Arctic flora. This circumstance might suggest that plant life was completely destroyed during the Ice Age. However, the circumpolar distribution and the considerable number of cases of identity with Tertiary fossil forms, on the contrary, speak for a persistence through the Ice Age in various regions.

Animal Life

Animal life, as well as plant life, is excluded from the ice-covered surfaces of the land and restricted to the tundra and the ice-free coastal regions, on the one hand, and the sea and its ice fields on the other. An adaptation to the landscape, which is mostly covered with snow, is the white color that many mammals and birds have either in winter,

like the ptarmigan and the Arctic fox, or all the year round. Still more general is the protection against cold. The land animals almost all have a thick coat of feathers or fur which is best developed in winter. Some also have a layer of fat under the skin, like the reindeer and a number of bird species in winter and particularly the sea animals. With the seal this layer attains a thickness of 10 centimeters, especially in winter. Other animals fall into a winter sleep or, like the

FIG. 5—A white Arctic fox on sea ice. Although the foxes are on shore in summer, living on lemmings and birds' eggs, they often spend the winter at sea, living, as parasites on the polar bear, on the remains of seals that he has killed. (Photograph from Vilhjalmur Stefansson.)

lemming, at least burrow into the ground. Others migrate southwards, like the reindeer and many birds; the former in spring migrates across the straits in the American Archipelago and from the Siberian forest into the tundra, and back again in the autumn. Many bird species of our coasts, like plover and snipe, have their breeding places in the tundra. On the water ducks, cranes, and swamp birds abound; in the willow bushes, insectivorous birds. From the eider duck, which Sverdrup considers the most interesting bird of the northern coasts, down is gathered, about a pound a year from fourteen birds. On the cliffs perch colonies of guillemots, auks, terns, and others, in hundreds and hundreds of thousands, and fill the air with their cries. Especially along the coasts that have horizontal strata, with steps like stories, are bird roosts to be found. Not the least important Arctic animal life is represented by the insects.

To be sure, they occur as relatively few species of butterflies, bees, spiders, and the like, but there are immense swarms of them, like the mosquitoes of Siberia, Greenland, and the Barren Grounds—in fact wherever water is found. They may make the Arctic summer, which inland is oppressive enough, a diabolical torture.

Of large mammals the one that ranges farthest north is the musk ox (*Ovibos moschatus;* Fig. 17, p. 66). Even in the meager meadows of northern Greenland this bovine species is able to dig out its food

FIG. 6—Reindeer on the snow-covered tundra. Although the photograph actually represents a doe licking her newly born fawn, it might also illustrate the manner in which reindeer feed on lichen under the snow cover. (Photograph from Vilhjalmur Stefansson.)

from under the thin cover of snow. But it is restricted to the American sector and to the eastern side of it. At Coronation Gulf it has already become scarce, and west of this locality it disappears. The wolverine extends not nearly so far northward. More Arctic in character and more generally distributed are the Arctic fox (Fig. 5), the lemming, ermine, wolf, and Arctic hare. In usefulness they are all outdone by the reindeer (*Rangifer tarandus*), the characteristic animal of the Arctic Regions (Fig. 6). The Eskimos hunt it because of its meat and hide, the Asiatics have long tamed it and used it as a transportation animal, in Alaska and Labrador also it has been introduced, and its meat is latterly coming into favor in civilized countries. Stefansson is even of the opinion that by the extermination of its enemies—hundreds of thousands annually fall prey to wolves—a vast pasture for the production of meat for civilized nations might be secured.

It is only in its seas that the Arctic Regions develop a great abundance of life. The greater and lesser animal forms that are dependent

for their fundamental food on plankton, which grows luxuriantly precisely in cold waters, flourish here in almost unbelievable numbers. If one remembers in addition that the birds mainly have their nesting places along the coast and that they are constantly flying over the waters and ice floes, then one will realize that the contrast between the interior of the land and the sea and its margins is especially marked. Accordingly the Arctic native, where water and land are intermingled as in the American Arctic, has found the basis of his existence more in the sea than on the land. Not only do such fish as the cod abound in immense numbers there, but also the characteristic large mammals. Of these the one that stays closest to the land is the polar bear; in winter he comes occasionally to the coast, but on the whole his roaming about is mainly done on the pack ice. He is circumpolar and strictly Arctic. In much larger numbers are present whales and seals, particularly the latter, now projecting their fantastic heads out of the open water, now sunning themselves on the ice and looking literally like mounds of flesh. In the winter they do not leave the ice, and when this is frozen over they keep blowholes open, through which the Eskimos spear them with special skill. The largest animal of this kind is the walrus. From all the animals of the seal family the Eskimo takes blubber, meat, and fur and makes use also of some of the bones and other parts for the manufacture of implements. Whales are of less value to him; whereas to civilized man this largest of animals has been one of the chief attractions that have caused him to seek Arctic waters.

Man

The Arctic peoples constitute a clean-cut conception also, like the Arctic animal and plant worlds. These regions support peoples who have received their mental and physical stamp from stern nature herself; in many traits these peoples are alike throughout the Arctic, in others they differ according to the major type regions. The inland-ice region may be left out of consideration; but there remain on the one hand tundra and on the other sea, ice, and coast. In the tundra it is the land alone that can afford a basis for human life; on the coast it is the sea to a greater degree than the land. Therefore the Eurasian and American sectors are fundamentally different; in the former man lives in the tundra and for long stretches keeps away from the coast and from most of the islands; in the latter, however, the Eskimo, while undertaking side trips into the continental tundra zone, has his main habitat along the coasts. Thus, Arctic man of Eurasia is an inland dweller, while his fellow in America is an island and peninsula dweller.

Both are nomads and base their existence on animals. Plants play but a secondary rôle in their economy; they are very little used

by the Eskimo (moss for lamp wicks, angelica as a delicacy), somewhat more by the Siberian. The latter, in the autumn, withdraws to the protection of the forest; here he finds berries, tubers, and nuts as additional food and wood for utensils, whereas the Eskimo is limited to driftwood and dwarf growths. The mainstay of economic life in the Asiatic realm is reindeer breeding, in the American the tribute of the sea. Hunting on land is merely secondary in the case of both peoples. Fishing in rivers and seas also plays its part, as, for example, with the Chukchis among Asiatic coastal peoples and with a number of Eskimo tribes. As to the kind of fish, salmon, cod, and halibut are preferred. With the Eskimos as well as with the Aleuts, Chukchis, and a few other Asiatic coastal tribes the chief game animal is the seal, on land the reindeer. The latter is therefore of great importance throughout the Arctic. Clothing made from its hide is unexcelled, while all the rest of the animal is utilized, even to the contents of the stomach, highly appreciated as a delicacy. The seal also is completely utilized as food, clothing, and fuel. Clothing consists of a double fur suit, to which the fox, wolf, bear, and other animals beside the seal contribute. Throughout the Arctic, meat is eaten raw, frozen, cooked, and rotten. Raw meat particularly is eaten in great quantities (as much as fifteen pounds per person in half a day) and a great deal of fat. As a result of such a diet, Arctic man has a well-rounded bodily form and because of his layer of fat can resist hunger for a long time.

Movement and mode of life primarily follow the laws of life of the animals, and these, in turn, the nature of the country. All Arctic peoples have accurate powers of observation of nature and acute senses. The Siberians have to seek food and protection for their herds and for this reason cover large distances on their reindeer and dog sledges. They migrate towards the north as a rule in summer and towards the south in winter. In summer their dwellings are light tents, in winter covered-over earth pits; if they are surprised by a storm they will quickly dig out shelter for themselves in the snow. Because of their hunting the Eskimos have a more varied seasonal life. The nature of the winter ice primarily governs their distribution, and the ice in turn is controlled by the outline of the coast, by currents, and by tides. Only in West Greenland have the Eskimos become distinctly sedentary; normally in winter they concentrate in the larger settlements and for the summer hunting disperse over wide areas. To the winter economy of their life belong the dog sledge and the winter house made of snow (igloo; Fig. 8) or of stones and bones; to the summer economy, kayak and tent (tupik; Fig. 9). The farther south one goes in Greenland, the longer do summer conditions prevail, until in the farthest south dog sledge and ice hunting disappear altogether. The same difference obtains between northern Alaska and the Aleutian

Islands. Hunting is given up entirely at the time of greatest darkness; a period of hunger has then often to be overcome. Numerous and remarkable are the hunting methods and appliances; alone the seal is hunted in a variety of ways at different times. The kayak (Fig. 7) remains the Eskimo's most brilliant invention; in it he moves about even in a heavy sea easily and skillfully, like a water animal, and dares to attack even the walrus. Next to the chase, handicraft of all sorts is

FIG. 7—Eskimo in kayak with harpoon attached by a line to an inflated sealskin to insure its recovery. (Photograph by R. J. Flaherty.)

the most characteristic activity; in this the Eskimo exhibits a truly remarkable skill, a genuine "culture of the hand" (according to Steensby). With his sparse resources of bones, stones, clay, driftwood, and less frequently copper and iron he is able to take care of himself in all situations, and if everything else is lacking he can even make a sledge out of a frozen musk-ox hide. The sureness and accuracy he displays in building a snow hut, which the European is able to do only after long practice, arouses admiration. "It is a pleasure to see how well a good builder cuts each block so that it just fits where he sets it. Atikleura is a prodigy at this work. Not one of his blocks ever breaks in pieces, although he appears to cut them out without any particular care. Just a cut here and there, then a kick, and the thin, neat block stands separated from the mass of snow. All the blocks from Atikleura's hand are so exactly equal in size that they look as if they had been accurately measured" (Amundsen).

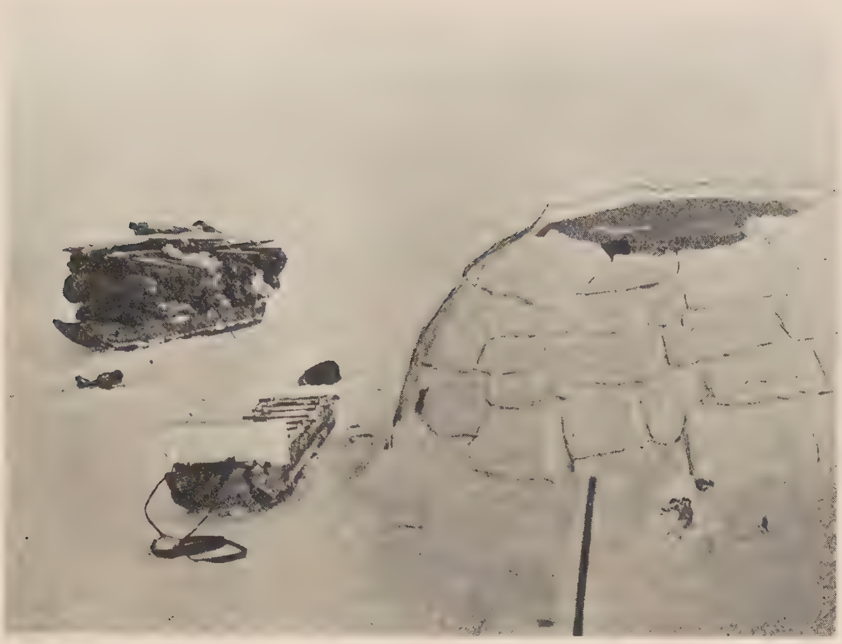


FIG. 8

FIG. 9

FIG. 8—A snow hut, or igloo, of the Copper Eskimos in process of erection. The builder is inside. Southwestern Victoria Island. (Photograph by Diamond Jenness.)

FIG. 9—A summer tent, or tupik, of the bow-using Eskimos. Coronation Gulf. (Photograph from Vilhjalmur Stefansson.)

The women make clothing and boots with really waterproof stitching. This, together with the cutting up of the game and the preparation of the food, is their main work. Trade takes place in a restricted measure between tribes; the reindeer and the coast Chukchis, for example, barter their pelts and fishes; the Eskimos have to acquire through exchange driftwood (which is rare in places), steatite, and copper; tobacco and other products of civilization spread eastward from Bering Strait. Within tribes a sort of communistic anarchy reigns. There are no elected chiefs, only sorcerers who enjoy a certain

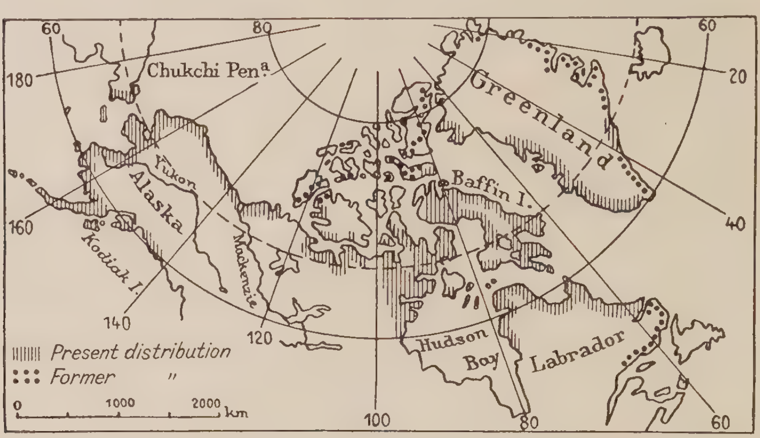


FIG. 10—Map showing the present and former distribution of the Eskimos. Scale, 1:75,-000,000. After Thalbitzer and later investigators.

authority. They are known as shamans among the Tunguses and as angekok among the Eskimos. Together the members of a tribe revel when there is abundance, and together they support want. Common to all Arctic peoples is a care-free, easy-going, good-natured, and happy spirit. There is no destitution among individuals as such, at times there is even great abundance; however, each person needs a great deal of sustenance space.

As to the number of the population, it is difficult to make a statement for the Asiatic sector; figures are usually given only for whole tribes, but these generally extend into the forest belt. In the Arctic fringe, the total population is probably hardly more than 30,000. This population is made up of Lapps, Samoyeds, Ostyaks, Dolgans, Tunguses, Yakuts, Yukagirs, Aleuts, Koryaks, and Chukchis—all of a decided Mongolian racial type but speaking a number of languages not closely related. The present number of Eskimos is hardly greater; Greenland contains most of them (14,000), and after that Alaska. The Greenland Eskimos constitute the eastern branch; those of Alaska, together with neighboring tribes extending beyond Coronation Gulf, the western branch. Situated between them the

Central Eskimos occupy the largest area but are the least numerous: they number about 3500 and are distributed among more than twenty tribes, the number of individuals in each tribe varying between 30 and 500.

In spite of their wide diffusion and small number, the Eskimos were once a unit in speech, culture, and race. This unity has chiefly persisted in speech; Rasmussen could understand all its forms from Greenland to Siberia. But culture and race have been strongly modified by the advent of white hunters in Alaska, Labrador, and Greenland, so that only the smaller group of Central Eskimos has maintained itself in relative purity, and even the remote Etah tribe on Smith Sound has been brought into continuous contact with civilization. The race originally had both Indian and Mongolian traits. As to culture, Steensby distinguishes between paleo-Eskimo and neo-Eskimo elements, of which the former developed in the central area from an Indian inland culture with adjustment to Arctic conditions, and the latter was brought in from eastern Asia by way of Bering Strait. However, there is also much to be said in favor of another opinion, namely that Alaska is the most logical original home of Eskimo culture, particularly in regard to the hunting of sea animals.

European economy has in the past profited greatly from the Arctic Regions, that is from the animal life of land and sea. The fur animals were a stimulus to exploration in both sections of the Arctic. Still greater profit came from the exploitation of the sea, as represented by the whale and seal fisheries, which began shortly before 1600 around Spitsbergen, being of great importance up to the period of mineral oils. The value of the Dutch catch during one century is estimated to have been $100,000,000. After the disappearance of the Greenland whale there, whaling in American waters began, which was carried on mainly by Americans and British and amounted to about $1,000,000,000 in the nineteenth century. This development has also nearly come to a close. Whereas during the height of whaling more than 600 vessels were active in the Arctic, at the beginning of the twentieth century there were scarcely 50 vessels. Much more important today is the seal fishery, especially in Bering Sea. It is only during recent decades that the mineral resources of Arctic lands have been brought under exploitation, especially gold in Alaska and coal in Spitsbergen. Now all free land has come under one or another political sovereignty. Thus the white man's civilization presses into this remote economic field and is gradually changing the life, trade, and form of settlement of the Eskimos. Nevertheless, they will never be able entirely to separate themselves from the bases of their existence, the ice of the coast and the distribution of game.

The Individual Regions

The Arctic Seas

BETWEEN land and sea in the Arctic there is outwardly no such sharp demarcation as elsewhere on earth. Where the edge of the land is flat the transition from the snow-covered land to the ice-covered sea is often imperceptible and the coast line hardly to be distinguished. Indeed, hundreds of kilometers have been traversed far out over the frozen sea by such men as Nansen, Cagni, Stefansson, Storkerson, and Peary. Ice-carrying currents as well as warm waters have climatic, economic, and commercial importance along the various coasts of Arctic lands. All these circumstances and the position of the main Arctic Basin enclosed by a girdle of land justify our beginning the section on individual regions with the sea.

Considered as a relief form the Arctic Sea differs from the main body of the Atlantic Ocean; for the characteristic feature of that ocean is that it is divided longitudinally throughout its whole length into two series of basins by a submarine ridge. This division stops at the rise which extends, at a depth of 600 meters, from the Faeroe Islands by way of Iceland to Greenland (unless Greenland be considered a continuation of the longitudinal submarine ridge of the Atlantic, and Baffin Bay and the North European Sea of the double series of basins). Baffin Bay is an isolated sunken fault block in the American oldland, and north of the Faeroe-Iceland ridge begins a single series of basins. It consists of three members. The first basin ends at a rise of 2300 meters depth between Jan Mayen and Bear Island; it may be called the Norwegian Basin. A second, the Spitsbergen Basin, follows and extends to a rise between Spitsbergen and northeastern Greenland which Nansen first conjectured and which the Duke of Orleans' soundings made probable. The third is the Fram, or Central, Basin. The greatest depth reached in the second basin is 3600 meters; the Fram Basin descends to 3850 meters. This basin is the largest, even if only the route of the *Fram* from the New Siberian Islands to Spitsbergen be considered as its median axis. Nansen believes it extends much farther out, beyond the pole to Beaufort Sea; whereas the late R. A. Harris from the range of the tides and the progression of the tidal wave deduced the existence of a land mass with a possible area of one and a third million square kilometers. Nansen, on the other hand, assumes that there is a current converging on northeastern Greenland from all sides of the basin, because Peary was deflected toward the east and the speed of the East Greenland Current is three or four times as great as was that of the drifting *Fram*. However, it should be said that, even allowing for

a current four times the width of the East Greenland Current, there would still be room for larger land masses or shallow water areas in Beaufort Sea. Peary's great depths between latitude 85° and the north pole (at which he sounded 2750 meters with no bottom) doubtless still belong to this basin. On the other hand, the sounding of nearly 3000 meters without bottom which Storkerson obtained in Beaufort Sea about 300 kilometers northeast of Point Barrow could as well belong to a separate basin, divided from the Fram Basin by a submarine elevation or by land. The new echo sounding of 5440 meters obtained by Wilkins above 700 kilometers due north of Herald Island may belong to the Fram Basin or to Beaufort Sea or it may indicate that there is only one continuous deep basin. It seems probable that all these basins are depressed crustal blocks with faulted borders. That is suggested not only by immense scarps such as those along the western coast of Spitsbergen but also by recent volcanic formations in many localities roundabout.

We know that a continental shelf exists around the central sea, but its actual border has been determined at only a few points. At all events it is wider on the Eurasian than on the American side. It begins in the southern part of Barents Sea with a width of 400 kilometers. The whole floor of this sea is but slightly submerged; it is the submarine continuation of the flat land about the Pechora River, crossed by a system of rills converging toward the west. The Kara Sea also is mainly shallow and slopes away from the Samoyed Peninsula toward a broad depression which parallels Novaya Zemlya. The broad floor of this continental shelf extends from the Kara Sea eastward along the whole Siberian coast to Point Barrow in Alaska, attaining a width of about 700 kilometers abreast of the New Siberian Islands. It is generally shallow but nevertheless free from shoals and thus has a remarkably level surface; the profile of the shelf along the route of the *Fram* for 400 kilometers west of the New Siberian Islands has a gradient of less than one minute of arc. At Point Barrow the shelf suddenly becomes narrow, its outer border being less than 100 kilometers from the coast. North of Grant Land Peary found this border less than 150 kilometers off shore. In the network of straits of the American Archipelago the depths vary greatly. Amundsen on his track met with such shallow and reef-beset waters that he could not have succeeded in accomplishing the Northwest Passage in a larger vessel than the *Gjöa*. Then again there are depths of several hundred meters, in Cardigan Strait even of 700 meters without bottom; this is therefore a fiord-like depression. Also in the Smith Sound passage the depths vary. Hudson Bay is entirely a shelf sea, Hudson Strait is a somewhat deeper furrow, Baffin Bay is a basin with depths attaining 1800 meters or more separated from the Atlantic Ocean by the broad sill of Davis Strait.

The bottom material of the Arctic Sea is very fine throughout. Its mineralogical composition is uniform; quartz ingredients predominate. Rocks were completely lacking in the bottom samples of the *Fram*. The organic ingredients are also slight, not more than five per cent even at the localities that are deepest and farthest from land. Evidently all sedimentation is slight, both from organisms in the water and from floating ice—organisms are few, and the floating ice does not melt much but is mainly carried off on the East Greenland Current instead.

The Arctic Sea in its hydrologic regimen as well as in its physiographic form and relations proves to be a subsidiary of the North Atlantic Ocean. From the latter the Gulf Stream goes by way of the Faeroe-Shetland furrow into the North European Sea, dominates its right flank, and throws off branch currents to the left which form large eddies with the cold waters of the Greenland side. The main mass of its waters is pushed farther northwards, on the one side into Barents Sea and on the other side along its outer margin to the west coast of Spitsbergen. The first of these two branches becomes scattered in the furrow system of Barents Sea and toward the northeast meets with cold waters; but it still keeps a path open toward Franz Josef Land which the seal hunters utilize, until it gradually succumbs to the polar water and ice. Not only can the mean course of these branches, which have been established by Knipovich and others, be traced and not only do they influence the climate of Novaya Zemlya, but, according to the present writer's investigations, even the most delicate pulsations of the Gulf Stream in the eleven-year climatic period can be felt along the ice margin of Barents Sea. The other branch flows along West Spitsbergen and makes the bays of its northern coast as accessible as those of the northern part of its west coast, whereas the southern part is washed rather by the cold and ice-filled coastal water which comes around the southern end of the island from the east. Similar current, ice, and communication conditions exist at the southern ends of Novaya Zemlya and Greenland.

The Gulf Stream drift submerges north of Spitsbergen and then becomes the massive warm and saline intermediate layer found by Nansen in the Fram Basin between the depths of 250 and 900 meters. The cold saline bottom water which lies under it likewise displays dependence on the North European Sea, where, according to Nansen, it originates through the cyclonic motion of cold and warm water, the cold element being supplied by winter cooling of the surface and the relatively warmer element by Gulf Stream contributions. The water lying above 250 meters depth is further divided into two layers, the upper of which is derived from the Siberian shelf sea. This upper water forced Parry, on his sledge advance north of Spitsbergen in 1827, continuously back to the south and crowded Cagni to the west-

southwest north of Franz Josef Land. Between Franz Josef Land and the north pole it drives forward toward the Atlantic outlet and then, as the East Greenland Current, forms the countercurrent to the Gulf Stream in the North European Sea and carries polar influences far forward to West Greenland and Labrador. By this route the *Jeannette* relics in 1884 came out of the Arctic Basin and arrived at Julianehaab in southwestern Greenland, and their course was followed by the *Fram*.

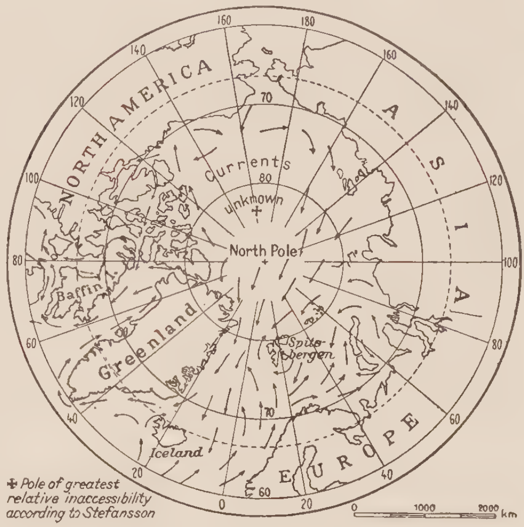


FIG. 11—Currents in the Arctic Basin. Scale, 1:100,000,000.

Thus through the north-south arrangement of basins the current system of the Atlantic Ocean is also stretched in a meridional direction. Because of this, polar deserts as well as habitable lands are wrenched from the usual latitudinal arrangement of the climatic belts to a greater extent than anywhere else in the world: Newfoundland, in the latitude of France, lies at the end of the drift-ice stream, and West Spitsbergen, far to the north, is readily accessible to civilization. The achievements of the discoverers were correspondingly different on the Northwest Passage and the Northeast Passage quests. Barents succeeded as early as 1596 in finding Spitsbergen; but on the opposite side, many voyages by the best men were necessary in order to unveil merely the coastal outlines of Davis Strait and Hudson Bay in relatively low latitudes.

The salient feature of the surface movements in the Fram Basin is evidently that westward drift that according to Nansen has a velocity independent of the wind of one-half to one nautical mile a day. From the shallow Kara and Siberian Seas the water flows toward this basin from the south and southeast. This westward-flowing current can be traced backwards to beyond the mouth of the Mackenzie. A drift cask reached the Atlantic Ocean from the Beaufort Sea presumably by this route; and the *Karluk* also, in 1913–1914, drifted from northerly Alaska toward Wrangel Island. But farther east in the American Archipelago the tendency of the flow changes decidedly towards the south and east, as the writer deduced in 1907 and as has been increasingly confirmed since then. In this area the main

currents in the straits are often obscured by local tidal currents. These may attain a high velocity, whereas in the central basin all motion, whether of currents or tides or waves, is reduced by the ice cover.

A widespread phenomenon along the Arctic coasts is the distribution, by the currents, of driftwood, which frequently is to be found on the shore or higher up in great quantities, overgrown with lichens. Everywhere the wood of coniferous trees predominates; in Spitsbergen, for example, to the extent of 85 per cent. The two main areas of origin, namely the great northern forest of North America and the *taiga* of Siberia, abound in this type. The driftwood of American origin on the one side of the continent spreads westward from the Mackenzie (Fig. 12) along the Alaskan coast, on the other it is carried by the Gulf Stream to Spitsbergen and Novaya Zemlya. The driftwood of Siberian origin is carried in the Arctic Drift to Franz Josef Land, Spitsbergen, and Greenland. Between both drift routes an interchange of material is possible; thus in Smith Sound American juniper wood was found which probably had been first carried by the Gulf Stream into the East Greenland Current and from the latter into Baffin Bay. In general the Arctic Drift has a greater share in the transportation and distribution of driftwood than has the Gulf Stream; and the primary land of origin is Siberia. Driftwood in great quantities is found on the north coast of Spitsbergen, which coast lies in the direction from which the wood comes. Along heavily ice-covered coasts driftwood is absent.

In addition to the relics of the *Jeannette* which reached southern Greenland, it was precisely driftwood of different kinds that afforded Nansen a clue to his brilliant recognition of the Arctic Drift. He thus wrote of a throwing-stick of foreign origin that had been found at Godthaab: "From later inquiries, however, it appeared that it must have come from the coast of Alaska in the neighborhood of Bering Strait, as that is the only place where 'throwing sticks' of a similar form are used. It was even ornamented with Chinese glass beads, exactly similar to those which the Alaskan Eskimo obtain by barter from Asiatic tribes and use for the decoration of their 'throwing sticks.' We may, therefore, with confidence assert that this piece of wood was carried from the west coast of Alaska over to Greenland by a current the whole course of which we do not know, but which may be assumed to flow very near the North Pole or at some place between it and Franz Josef Land."

The most characteristic feature in the realm of the Arctic seas, along the coasts as well as far from land, is ice. It forms on the surface of the water and increases quickly downwards to a maximum thickness of 3 meters or more. Nansen met with ice 3.65 meters thick. From

Fig. 12

Fig. 13

Fig. 12—Driftwood on the lower Mackenzie River near old Fort Good Hope (67½° N.). Practically all of the driftwood on the Mackenzie comes from its western tributaries, especially the Liard. (Photograph from E. M. Kindle.)

Fig. 13—Driftwood at the mouth of the Kolyma River. (Photograph from N. A. Transehe.)

the middle of winter until the end of May it changes little; in June or July the thaw generally sets in. This must be caused rather by radiation than by the warmth of the air because temperatures above 0° C. do not often occur (Fig. 14) and can be produced only through warm winds coming from elsewhere. Only in the marginal areas, for example in the region of the East Greenland Current, the temperature

of the air in summer may be many degrees—as many as 8°—higher than that of the water. Other factors determine the time and the rate of melting: tides, melted snow water from the land, snowfall, etc. If, for example, much snow falls in the autumn, the ice will grow less thick, and conditions in the next summer will be more favorable for melting. Occasionally the snow does not melt completely for years, and a sort of ice (*sikussak*; see Fig. 15) with some characteristics of land glaciers forms in the sea, as is reported from north of Greenland. Over large areas the year's ice disappears completely. However, that varies according to the locality and the year, so that the accessibility of a given locality baffles all calculation. The openings that form, too, are always limited, and changeableness is the main characteristic of the ice. In no summer does the Arctic Basin become wholly free or even half free; and, furthermore, the ice disappears only partially by melting where it is, but mainly by being carried away in the East Greenland Current. Altogether the ice of the open sea is, in spite of the apparently continuous cover, in constant motion, partly as a result of the drift as a whole and partly more locally as a result of winds and tides—often it shows a tendency to become denser and looser respectively twice a day. Throughout all of these movements it is also subjected to pressure and passes from the form of flat and floe ice into that of pack ice (hummock ice in English, *toros* in Russian).

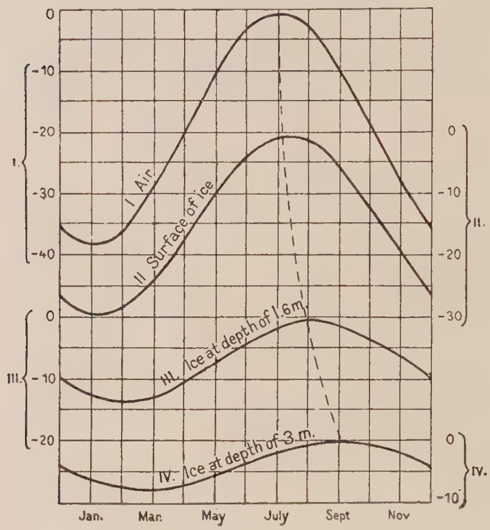


FIG. 14—The annual march of the air temperature over the Arctic Sea and of the internal temperature of the ice cover of that sea along the drift route of the *Fram*. The scale (in degrees C.) shifts for each curve as indicated on the margin by a corresponding Roman number. The lag in the maximum temperature of the ice as compared with the air is brought out by the dotted line.

The gigantic battle of natural forces leading to the formation of pack ice has been vividly described by Arctic travelers again and again. On the basis of these descriptions the process may possibly be summarized as follows: As a consequence of wind and waves the thin, widespread ice cover breaks open here and there, and the pieces then freeze together again or, if there is stronger motion, are wedged into each other, thrust over each other, and then cemented together into a chaotic whole—the pack ice—by melted-ice water or sea

water between the pieces and by newly fallen snow. Again, through a heap of this sort, a crack, an open lead, or an ice hole may form. These ice holes also may disappear; indeed sometimes they open and close so rapidly that a vessel may in a few moments find itself not in an ice-free fairway but in a tangled mass of piled-up blocks which are in battle against themselves and against the vessel. With the progress of winter the pack becomes more and more consolidated; at the same time the quiet apparently increases; for days everything may preserve a deathlike rigidity. Suddenly a sound is heard that is all the more uncanny by contrast: "whistling, singing, clapping, crashing, the oddest sounds"—these are the precursors of the real ice pressure and formation of pack ice from which develop mounds and walls as much as 6 meters high above the water. A storm may come up and unleash a struggle in which whole fields are driven one over another and pushed up vertically, then sink into ruins, and are packed together anew. Mile-long cracks zigzag across the ice and go right through mounds and consolidated pack, however firmly it may be cemented. In the next moment the rift may close again and a mighty ice field approach with great masses of ice heaped upon it, collide with the next field, and bore itself into it, the fragments whirling above and below the edge with a crash. The edges buckle up to form walls and towers, and immense pieces rear themselves up on them and then crash down, every piece an enemy of the other, so that in this wild battle everything sways, crashes, rumbles, groans, and sighs.

The final result of this constant interplay of building up and breaking down is an increase of the whole mass of ice. This mass has therefore reached its highest stage of development when at the end of the polar night the sun pours forth its first rays upon it. With that moment there suddenly begins the second period in the life cycle of this sea-ice colossus, namely that of decay. Evaporation, to be sure, works even during the winter night, and this process increases rapidly toward spring. But thaw is the main decomposing agent. It begins about in May and then develops an extremely rapid effectiveness as a result of the continuous radiation of the no longer setting sun. Everywhere water runs and flows on the wide hummocky surface; waterfalls, brooks, and lakes form on it; leads and ice holes open up roundabout; all angles and corners are rounded off; castles and towers fall; and rising fogs everywhere betray the fresh wounds. Even in the water the dissolving process takes place, and more actively in water that is in movement; most actively therefore in the surface layers with their waves and breakers. Thus it happens that in the separate pieces of ice a notch is formed at the water line. During this cycle the ice of the Arctic Basin is therefore not completely destroyed but is reduced, rather, to a skeleton, as it were, until with the sinking of the sun the process of accretion begins again.

Because of the offshore drift the ice of the Siberian Sea is comparatively light and thin, whereas that off northern Greenland and Grant Land (Fig. 15) is the heaviest and oldest known. This is because the whole drift sets strongly in that direction, depositing the ice there and pressing and packing it together. It is from this region therefore that Nares in 1876 brought back the conception of "paleocrystic ice" instead of that of an "open polar sea" which he expected to find. Today in reviewing the expeditions of the last thirty years this local differentiation in the formation of ice can be followed throughout the Arctic Basin. In the highest latitudes the ice is relatively level; thus to their good fortune Peary, Cagni, and Stefansson found it on their sea-ice journeys. Nansen, too, whose drift led far from the coast, found the pack-ice ridges not higher than 9 meters and called those higher than 7½ meters rare exceptions. The nearer one comes to the windward coasts of the great Arctic Drift the greater become the pressure ridges and the more frequent and the larger the leads between them. Thus Cagni near Franz Josef Land met with ice walls over 10 meters high. "One might say that they were the ruins of some gigantic city, with its monuments overthrown, its church towers destroyed, and its palaces demolished all at one blow, a true image of chaos under its most dreary aspect" (Luigi Amedeo of Savoy). From North Greenland, finally, and the outer coasts of the Archipelago, which are even more exposed to the drift, Sverdrup, Peary, and Stefansson unanimously reported still more gigantic ridges, up to 25 or 30 meters in height. They are everywhere arranged more or less parallel to the coast and at right angles to the direction of the wind; likewise the channels, the largest of which, Peary's "Big Lead," is said to remain permanently along the edge of the continental shelf north of Grant Land. The pressure ridges, a wild pile of angular and smooth blocks through which a path had to be chopped with the ax, and the leads, with their uncertain openings and closings, fill Peary's vivid descriptions of his march to the pole.

The ice along flat coasts, especially that along the Siberian shore, is often soiled with mud and sand as a result of storms and hence is dark. Farther out it remains clean, but discoloration can also take place in other ways, particularly on the surface of old snow and ice, as these supply a culture medium for numerous microphytes. At the bottom of melted-ice water puddles brown algae grow in abundance.

Along the coasts at the beginning of winter there is formed the typical phenomenon of the ice foot, very narrow along steep coasts, wide where the water is shallow and it can rest on the bottom. The tides are the chief originating cause. It grows upward to highest water mark, and its edge breaks off abruptly to the outer free sea

ice, which rises and falls with the tides. Along the edge of the platform pressure ridges form, often several in the course of the winter, one behind the other. Under certain conditions the ice foot can maintain itself through the whole summer. Generally, however, with the arrival of spring, it is subjected more and more to attack by stand-

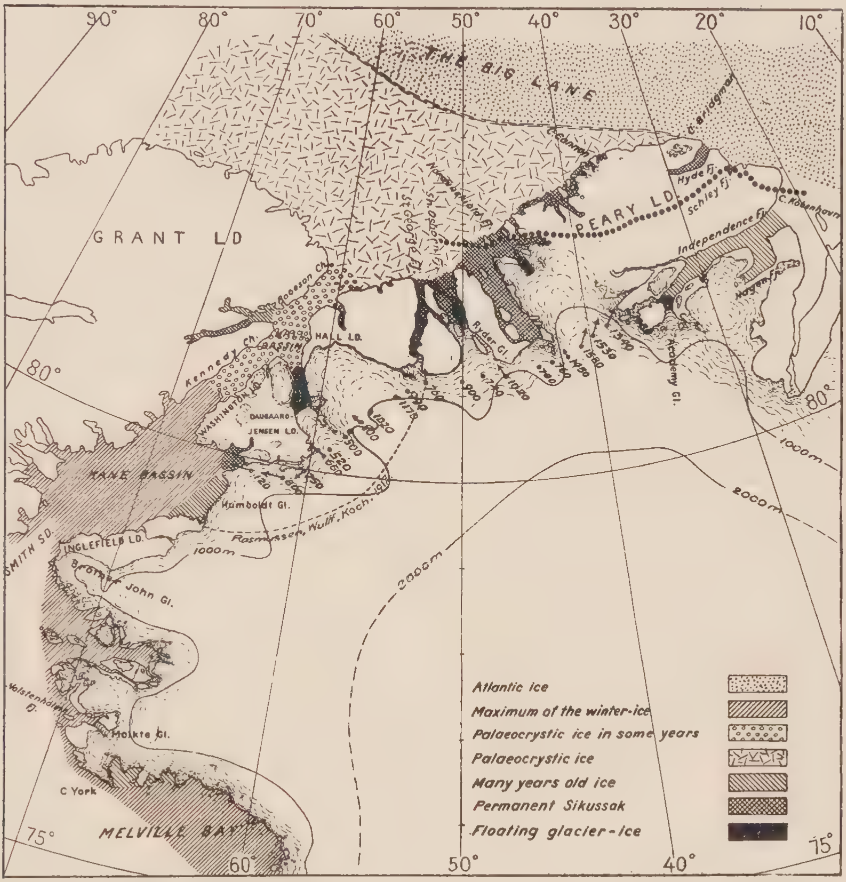


FIG. 15—Map by Lauge Koch showing the types of ice (see legend) off the coasts of northern Greenland and Grant Land. Scale: 1 : 9,700,000. Note the paleocrystic ice and Peary's Big Lead, or Lane. (Sikussak is very old sea ice—at least 25 years old—formed in quiet fiords. In granulation it resembles glacier ice because of the freezing on its surface of snow-water pools that have no outlet.)

ing and running water from above and by the increasingly warmer sea water from below until it finally breaks up. There then develops the narrow lane of land water, in front of which the heavier ice hovers outside. This lane is of great importance for the passage of vessels.

The limit of ice is a zone of marked variability of climatic phenomena—of temperature, fogs, and winds. From beyond the range of vision the larger ice masses announce their presence by the iceblink—a brightly shining strip in the sky over the ice. The extreme limit

of drift ice runs from the Grand Banks of Newfoundland by way of southern Greenland and Iceland to the Faeroes, but from there it bends far northward with the Gulf Stream waters to about Bear Island. In the spring this boundary, north of the Faeroes, recedes somewhat to a position extending from Jan Mayen northeast towards Spitsbergen. In the summer, as a rule, the whole west coast of Spitsbergen becomes free of ice. East and north of southern Greenland the ice is everywhere mainly pack and floe ice, at all events sea ice; and glacier-derived icebergs are intermingled only to a small extent. By contrast icebergs play the leading part on the west coast of Greenland and in the currents which flow away from there, particularly the Labrador Current, which carries them to Newfoundland and into the Gulf Stream. These drifting colossi are often 50 meters high, sometimes even 100 meters or more, and assume fantastic forms. "There is nothing between heaven and earth that has not taken on form in the mighty fantasy of cold" (Sverdrup). They come from the great fiords in middle western Greenland that tap the inland ice. Their occurrence so far south as Newfoundland is, so far as their size, the time of their appearance, their duration, and their southern range are concerned, dependent on the general weather of the season. The disintegration of icebergs takes place not only through slow melting but rather by breaking up into pieces, partly as a result of turning turtle and colliding with each other, partly as a result of internal tension, which acts like an explosive force and is relieved with a deafening sound.

In accordance with the distribution of currents and ice there have been, in the history of Arctic exploration, three preferred routes of entry. One is the region about Bering Strait, in the rear of the great Arctic Drift but still in relatively low latitudes and in cold waters in the neighborhood of poles of coldness. A second consists of the Franz Josef Land and Spitsbergen archipelagoes, representing far advanced bases accessible through warm waters, from which progress must be made against the current and from which attacks upon the pole have been made by various means. The third gateway is Smith Sound, which because of the West Greenland Current, the North Water, and the open water along the shores of its narrows, makes it possible to establish far northern bases that have proved suitable for the exploration of the adjacent lands over a wide radius as well as the attainment of the pole itself over the heavy but firm ice. The largest area of unknown territory lies in the neighborhood of the first gateway; here Stefansson prior to the Amundsen-Ellsworth-Nobile transpolar flight, which bisected this area, placed the location of a region of relative inaccessibility with its center in latitude 84° N. and longitude 160° W.

The Arctic seas in the abundance of their organic life stand in contrast to the waters of lower latitudes. Not only do the great

fishing banks lie in the marginal belt of the Arctic, off Newfoundland, Labrador, Iceland, and the Murman Coast, but here also lie the hunting grounds of seals and whales. Their abundance is based on that of small animals and plants. Of marine algae 124 species are known from the coastal area of East Greenland. Diatoms are richer in species in the cold seas of East Greenland than in the warmer waters of West Greenland. The forms most characteristic of the Arctic are crustaceans and sea mammals. The former are very rich in species, and on them the latter are dependent; for whales as well as otaries and seals, but not the walrus, feed primarily on fishes and cephalopods, which in turn need crustaceans for their nourishment. The mammals have by now been largely hunted out of the extreme marginal area. The whale fisheries died out first near Norway, then near Iceland and the Faeroes, finally about Spitsbergen and the more southerly parts of the American Arctic. Only the extreme northerly parts of the American Arctic as well as the Kara Sea are not yet completely emptied.

In the Fram Basin also crustaceans are by far the predominant fauna (49 species), but the number of individuals is here much less than in the marginal regions. The reason for this is the dearth of plant life, and this in turn is based on the meagerness of light. Thereby the waters retain in abundance the elements necessary for the maintenance of life, and, wherever in the marginal areas they are freed from the light-robbing ice cover, it becomes possible for organic life to develop all the more actively, especially in the spring and summer. To this theory, developed from the findings of the *Fram*, Stefansson places in opposition his new conception of the abundance of life even under the ice. That seals occur everywhere where the ice breaks up in leads and thereby makes it possible for them to keep open their breathing holes may be conceded; but even according to Stefansson there are ice deserts in between, and he himself experienced hunger stretches in carrying out his method of "living off the country" on the ice of Beaufort Sea. Thus the earlier conception of great scarcity of life in the Arctic may be somewhat modified but not entirely destroyed. Worthy of admiration, however, is the entirely new method of exploration which Stefansson was able to base on this modified conception.

Even on the ice, life still occurs in high latitudes; Peary met with fresh polar bear and fox tracks in latitudes 86° to 88°, but these are exceptions. Somewhat more abundant is the life in the air over the ice. Three-hundred kilometers northeast of Franz Josef Land the *Fram* met with various bird species, none, however, in great abundance. The fulmar (*Fulmarus glacialis*) has been seen beyond 85°. This and the ivory gull (*Pagophila eburnea*) were the birds that Nansen met with most frequently on his sledge advance.

Spitsbergen (Svalbard)

More than any other polar land Spitsbergen has attracted international competition, first in Arctic fisheries and then in scientific investigation. In spite of its high northern position between latitudes 76° 25′ and 80° 50′ it is brought into the orbit of civilization by its nearness to Hammerfest, but 500 kilometers away, and because of the fact that the Gulf Stream keeps open the sea way to its western coast. It was discovered at the end of the twelfth century by a Northman who had been driven out of his course, probably by southwest winds, on to this shore (hence the name Svalbard, "cool coast," recently resuscitated since the group has come under Norwegian suzerainty) and was rediscovered in 1596 by Barents. It was on this coast that an excellent seventeenth-century observer, the German ship's barber Friedrich Martens, became acquainted with the character of the Polar Regions, of which his book (1671) offers a remarkable description for that time. Also along its western coast Hudson in 1607 and Parry in 1827 sailed on their polar advances; at its northwestern corner Andrée established a base for his balloon flight, Zeppelin for his dirigible attempts, Amundsen and Byrd for their airplane flights towards and to the pole, respectively, and Amundsen, Ellsworth, and Nobile for their transpolar flight.

The first surveys of Spitsbergen were made by the younger Scoresby, who, in his seventeen voyages there, established the basis for a more exact knowledge of the group. This knowledge was deepened by the investigations of the Norwegian geologist Keilhau in 1827. and by those of the scientific staff of the French vessel, *La Recherche*, in 1838 to 1840. The chief part in scientific research, however, was taken by Sweden, at first in 1858 to 1879 by the epoch-making studies of Torell, Nordenskiöld, and others, and since the end of the century by Nathorst, De Geer, and Högbom; to these should be added the names of Norwegian geologists, such as Hoel. Our knowledge of the archipelago was extended in 1870 by the discovery of King Karl Land by Count Waldburg-Zeil and by Heuglin. Precise topographic surveys and many other determinations were made at the time of the Swedish-Russian measurement of an arc of the meridian from 1898 to 1902. In the interior the English alpinist Conway has contributed since the nineties to our knowledge of the topography and glaciation. Extensive surveying has been carried out since 1906 by Captain Gunnar Isachsen on the cruises of the Prince of Monaco. Maps on the scale of 1:100,000 and more detailed ones on the scale of 1:20,000 are available, some of these having been made on the basis of airplane photographs. Even out-of-the-way Northeast Land has been traversed (by Nordenskiöld) and circumnavigated. Its eastern coast, difficult of access in accordance with the well-known contrast in Arctic lands between the west and east sides, was accurately located

by Worsley in 1925. Nevertheless this island is still the least known of the archipelago.

Belief in a connection between Spitsbergen and Greenland long prevailed. After the insular nature of the archipelago had been determined about 1650 it nevertheless continued to be known down to the nineteenth century, especially among the English, as Greenland. Indeed, the nomenclature of Spitsbergen is characterized by complete chaos, different names being employed for the same locality, partly at the same time and partly consecutively. This is to be explained by the fact that many nations came in contact with the new land at the time of the whale fishery.

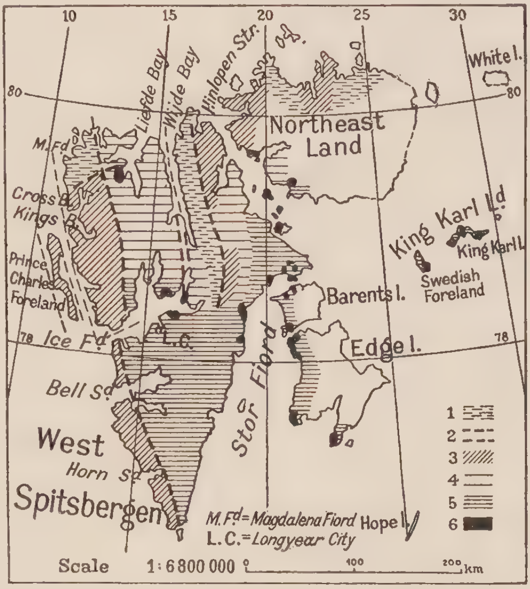
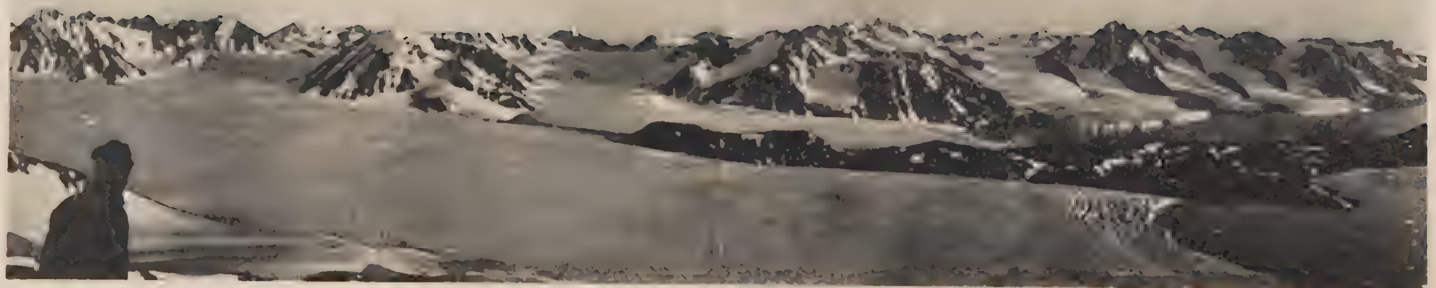


FIG. 16—The structural areas of Spitsbergen. 1, basement complex (granite and gneiss); 2, faults; 3, folded belt (Hecla Hook formation); 4–5, plateaus (4, Paleozoic; 5, Mesozoic and Tertiary); 6, extrusives (diabase and basalt). The eastern coast of Northeast Land has been revised according to the Worsley and Algarsson expedition of 1925.

The archipelago lies on the European continental shelf. The main island consists of wedge-shaped West Spitsbergen, pointed to the south and indented by fiords. It is surrounded by other islands: to the west, the narrow 80-kilometer-long Prince Charles Foreland; to the northeast, separated by the fiordlike Hinlopen Strait, Northeast Land; and to the southeast Barents and Edge Islands, both separated from the main island by Stor (Great) Fiord. Somewhat farther off to the east lie the three small islands constituting King Karl Land, namely King Karl Island, Swedish Foreland, and Abel Island, while some distance southeast of Edge Island is the small Hope Island. All these islands, together with many small ones, occupy a total of 68,000 square kilometers. The separating arms of the sea, likewise the main fiords, are structural in origin. On the west side, fiords penetrate in an east-northeast direction, farthest in the case of Bell Sound and the much-branching Ice Fiord. At right angles to this axis lie those fiords that reach deep into the main island from its northern coast—Wijde Bay and Liefde Bay. About parallel to their axes and east of



FIGS. 17 and 18—Mountains in the western zone of Spitsbergen.

FIG. 17—View looking west across Grand Glacier, debouching into Red Bay (extreme right) the next fiord west of Liefde Bay. Glacier-furrowed alpine topography in the gneiss and granite area of northwestern West Spitsbergen (for location, see Fig. 16; for map representing this type, see Fig. 19). (Photograph by Gunnar Isachsen, August, 1909.)

FIG. 18—Panorama of Horn Sound at the southern end of the western coast of West Spitsbergen. Mountains in the folded zone. (Photograph by Adolph Hoel, 1918.)

them, Hinlopen Strait and, as its continuation, the flank of Edge and Barents Islands strike south-southeast and north-northwest; so do, to the west of them, the 15-kilometer-wide Foreland Sound graben and the Prince Charles Foreland horst; likewise the whole western coast of the main island and the longitudinal faults that parallel it at no great distance in the interior; and finally the conti-

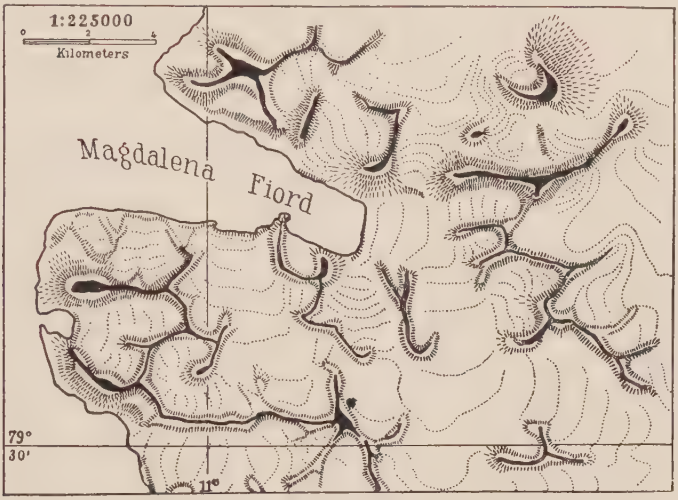


FIG. 19—Glacier-drowned alpine topography with projecting peaks and crests. Magdalena Fiord (see Fig. 16) in the gneiss and granite area of the northwest corner of West Spitsbergen.

nental shelf slope in front of Spitsbergen and of the entrance to Barents Sea. This direction, therefore, dominates in the tectonics of the archipelago.

Any one sailing along the west coast receives the same impression that led the Dutch discoverers to the choice of the name. Sharp, almost delicate, mountain pyramids and narrow crests follow one upon another, and between them glaciers reach the coast (see Figs. 17 and 18). The mountains are of moderate height only, generally under 1000 meters (the highest being Hornsundtind, 1430 meters, at the southern tip of West Spitsbergen), but with sharp outlines and enveloped in a mantle of angular débris—alpine massifs sunk into the sea up to the ends of their glaciers. The interior plateaus are clearly differentiated from the mountains; they do not often exceed 600 meters in elevation (Mt. Eidsvoll, east of Cross Bay, 1450 meters). This contrast is based on the geology, namely a folded zone in the west as against horizontal strata in the interior. In the western zone lie the great Silurian sediments of dolomitic character as well as mica schists and quartzites, all of which have been affected by the Caledonian folding and are permeated by granite intrusions. These

sediments are known as the Hecla Hook formation and strike parallel to the coast. To the east there follows a region of old-faulted plateaus in which the old folded basement complex is covered discordantly by deposits of all geological ages. Paleozoic (beginning with Devonian), Mesozoic, and Tertiary rocks occupy the surface in the form of sandstones, conglomerates, limestones, and shales—the older formations predominating in the north, the younger in the south. They have later been only secondarily affected by folding, more by faulting and drag. They are consequently steeply inclined in some places only; in general they are nearly horizontal.

FIG. 20—Plateaus in the interior of Spitsbergen. Looking down (southwest) the Mälar Valley across Advent Bay. Advent Bay is the third major indentation on the southern side of Ice Fiord back from its mouth (see Fig. 16). On it lie the coal mines at Hiorthaven (formerly Advent City) on its northeastern and at Longyear City on its southwestern shore. (Photograph by Alfred Koller, 1917.)

These table-, box- and coffin-shaped landforms, with their generally bare steep slopes, displaying delicately etched strata above and covered by an evenly sloping talus mantle below, impart an extremely uniform appearance to the central and eastern areas. The step structure of the slopes is lacking only in the Devonian old red sandstone in the north. The surface of the plateaus is covered with ice and snow or overspread thickly and closely with angular pieces of rock like a stony desert; at all events it is level and monotonous. These castellated plateaus, separated by wide rectilinear valleys and fiord heads, notched by side gorges which branch from them at right angles, remind one of the blocks of houses in a city. This arrangement led De Geer to suggest a novel geographic terminology. He calls the plateaus "quarters" (Colorado Quarter, Temple Quarter, etc.) and assigns numbers like the house numbers on a street to the sections between the notches (see the map, Fig. 21).

In among and between the two zones of landforms—the one on

folded, the other on massive horizontal structures—appears the basement complex; it consists mainly of granites, gneisses, and crystalline slates. On the main island it occupies a large area in the northwest corner and parallels the long eastern coast of Wijde Bay as a horst extending from north to south and attaining an elevation of 1730 meters in Mt. Newton of the Chydenius group. In these areas a third landform may be recognized: undulating and dome-dotted plateaus with rounded edges and steep but unterraced slopes. *Roches moutonnées* forms are the most frequent, fell fields not uncommon. On Amsterdam Island off the extreme northwestern corner of West Spitsbergen this blocklike and rounded form of the landscape is clearly apparent.

In addition, relatively recent eruptions have furnished structural elements in the landscape; however, these are rather local. Thick diabase dikes and other diabase intrusions occur here and there in an eastern zone in the Mesozoic and Paleozoic strata and in part shape the surface features. In the northwest, in addition to such intrusions and lava fields, there have been found along a prominent fault line Quaternary volcanic cones consisting of ashes, lapilli, and slag (1000 and 500 meters high). There are also in the vicinity hot springs (28° C.) with calcareous sinter deposits. The islands of King Karl Land are covered with basalt and owe their existence to the protective influence of this cover alone.

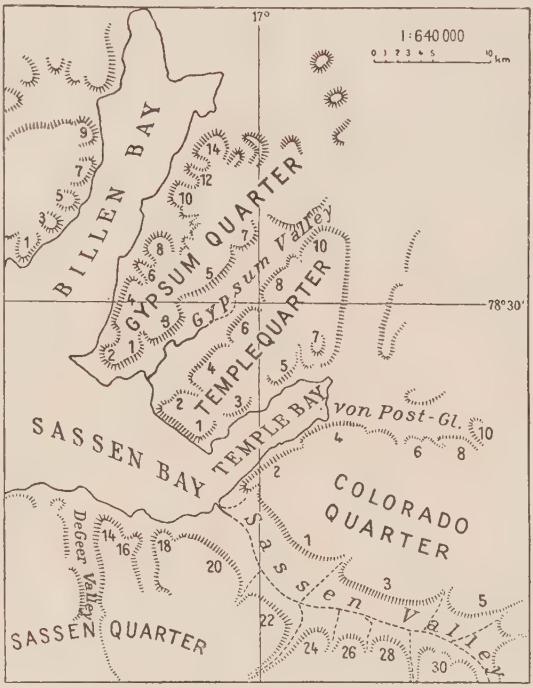


FIG. 21—Plateau region at the head of Ice Fiord.

Finally, a distinctive landscape is formed by the coastal plains or forelands. Long stretches of the coast as well as tracts along the interior of the fiords lie at an elevation of 20 to 30 meters above sea level. In places they increase to a width of several kilometers, in the case of Daumann Spit, projecting between Ice Fiord and Foreland Sound, even to ten kilometers. The foundation consists of bed rock; the surface, however, consists mainly of detrital matter

from the country rock as well as glacial erratics and especially marine sediments. These lower plains represent abrasional surfaces which Drygalski interprets as of preglacial or at least glacial origin. Above these plains there are often found higher narrow terraces with elevations up to 130 meters above the sea. They may be of late or postglacial age. Even driftwood has been preserved on them, in King Karl Land at an elevation of 40 meters. Along the shore driftwood is abundant, especially on the western and northern coasts; and in the past countless fishermen wintering there have had to rely on it for fuel.

Even glacial influences have not obliterated the main contrast between the two types of landscapes: plateaus and flat domes on the one side, peaks and sharp crests of the Hecla Hook zone on the other. That glaciation was once heavier is certain. Deposits of the Glacial Period have been found at least 300 to 400 meters above the surface of the present glaciers. However, the smaller traces are often effaced, both through the present effect of frost and insolation and through the former activity of the sea at a higher level.

The present glaciation (Fig. 17), taken as a whole, does not present the unbroken character of inland ice; in many cases the ice is still in a state of recession. The snow limit lies at 400 meters on Lilliehöök Glacier (79⅓° N.) at the head of one of the arms of Cross Bay and probably at not less than 600 meters in southern Spitsbergen. Many of the interior sandstone plateaus are almost entirely free from ice because, owing to their level character, they are quite unprotected against the winds. Wide valleys also, like the Sassen Valley (Fig. 21), are without ice. On the other hand, the undulating Archean plateaus afford numerous places for the development of ice caps and ice fields, the more favorable conditions for this being present in the Hecla Hook Mountains, where, however, no continuous ice sheet results. Two types of ice forms, therefore, dominate the landscape. The first is alpine valley glaciation, particularly in the Hecla Hook zone. Here row after row of ice tongues occur, separated from each other only by narrow ridges. Down the valley floors the tongues advance slowly, less than a meter a day, to end in ice walls 20 meters high—impressive to view but too low to create icebergs of any consequence. The second glacial type is upland ice, similar to that found in Norway, covering the Archean. The upland ice of Spitsbergen becomes thicker as one goes northeast and, in New Frisia and still more in Northeast Land, approaches the inland ice type, which here for long distances breaks off in cliffs 30 to 40 meters high and constitutes a surface with a mean elevation of 600 meters. In the west, the valley glaciation is intensified by convergence and comes to have a certain resemblance to the piedmont glaciation of Alaska. In addition to these phenomena there are, according to Drygalski, niche glaciers and terrace ice. The

latter imparts a very characteristic expression to the plateau slopes around Ice Fiord, by covering the shelves with strips or treads of ice that correspond to the projecting tops of the resistant formations. Often only snow fields lie in the funnel-shaped gathering fields at the heads of the parallel erosional depressions. These numerous regular white spots relieve the stereotyped picture of fiord and valley along the inner parts of the western coast.

Because of the low temperature the ice-free ground of Spitsbergen is characterized by special phenomena, such as angular detritus, which is widespread, polygonal soil, stone rings and nets, flowing soil (solifluction), and ground ice, which last is found especially in level places and on permeable strata and is possibly still being formed from ground water. Summer insolation may contribute to the formation of detritus, but either frost or melt-water or both together are fundamentally associated with its formation as well as with all the phenomena that have been mentioned. By contrast, running water plays a lesser rôle in the landscape and the individual landforms of Spitsbergen. The brooks branch out in short, wide valley floors between the fiords. Only in summer small quantities of melt-water flow down the steep slopes of the plateau in narrow crevices and carry down loosened rock material. It is by permeating the ground—an areal action as compared with linear erosion—that water most largely affects the landforms. This permeation makes the valleys impassable during the thawing of the snow and emphasizes the sharp contrast between the lowlands and the hard, angular, and jagged forms of the uprising rock walls.

The distribution of land ice as well as sea ice marks the archipelago as a climatic corner post. On the northeast the group is subjected to extreme Arctic influences: on the west it is reached by the last remnants of the Gulf Stream drift. This current keeps open Whaler Bay, as the broad reëntrant in the pack ice west of Spitsbergen has been known to sailors for centuries, so that the harbors of the west coast are, as a rule, accessible for about four months, especially the more northern ones, because the polar floe ice is brought in from the east by the current that turns the southern corner. On the west even in winter the ice barricade does not become very heavy, whereas Stor Fiord is often blocked even in summer, and Hinlopen Strait remains completely inaccessible. Not infrequently whalers are cut off by the ice in Stor Fiord and forced to winter. Northeast Land has been circumnavigated but twice, and in 1912 it proved fatal to the expedition of Lieutenant Schröder-Stranz.

The mean annual temperature at the different stations of Spitsbergen lies between $-8°$ and $-10°$ C. Only three, at the most four, summer months have a mean above the freezing point, that of the warmest month being $4°$ or $5°$. Temperatures between $10°$ and $15°$

are, however, not rare in summer, particularly when the föhn wind blows, and the ground may thaw to a depth of 20 to 70 centimeters. The fiords of the west coast freeze up at about the winter solstice. Curiously, January is almost always warmer than December, and the lowest temperatures do not occur until February or March, that is at the end of the dark period, which lasts from the middle of October to the middle of February. The mean of the coldest month generally lies between –20° and –25° C. However, temperatures above the freezing point occur in almost every month; in the dead of winter a considerable local thaw may set in anywhere. The winter temperatures, indeed, undergo a wide range, and the diurnal variability during that season is about five times as great as in summer, which has a uniform warmth. In a word, great irregularity is characteristic of the weather of Spitsbergen during the greater part of the year. Barometric depressions from the North European Sea pass now to the southward, now to the westward, and bring winds from all directions, which are partly warm and partly cold and which veer now clockwise, now counterclockwise. On the west coast the wind velocity may vary greatly within a small space. Often the cold uplands send out violent and sometimes persistent winds through the long valleys and fiords, as, for example, the Sassen wind. They are part of the general air circulation and are caused by the "lows" of Barents Sea, but they are locally intensified by the valley troughs. Fog is frequent on the coast as a consequence of the mixture of the warm sea air and the cold land air. A little distance inland fogs are much rarer. Precipitation likewise is most abundant on the west coast. However, even here it does not amount to more than 200 millimeters a year. Toward the alimentation of the glaciers the fogs, which condense as hoarfrost, contribute another small amount. The eastern side of the archipelago is drier, clearer, and colder, especially in winter.

Plant life is developed more abundantly in the interior of the fiords than on the outer coasts, where fog and clouds as well as the heavier burden of snow retard it; however, this is only a difference in degree. Elevation above sea level has remarkably little influence; plants that grow along the shore also occur 600 meters higher. Rather, vegetation is primarily differentiated according to the slope of the ground, as it is this element that determines the heat radiation and also the water run-off. On the flat upland depressions there are moors and swamps with only a few of the higher plant species. On the slopes, however, particularly where melt-water trickles down, and on southern exposures, a wide range of color, size, and species develops, as in the case of the red saxifrage (*Saxifraga oppositifolia*), of which whole beds occur, mountain anemone, and many other flowering plants, among which woody shrubs, such as *Salix polaris*, are

interspersed. On taluses and moraines grasses and reeds make up the facies. In the wide lowlands the formation is mainly grass and tundra with its brown-green mosses and lichens, among which here and there patches of flowers are interspersed or occasionally polar meadows appear. Some valleys are great reindeer pastures. Where low annular ridges cover the ground the mosses are more dense on them, or rather on their inner edges, than on the enclosed ground spaces. Plant life is sparsest in the interior areas wherever there is a relatively heavy ice cover. Nevertheless, even on the ice-surrounded mountain peaks vegetation is not entirely absent; the hardy Arctic poppy is to be met with nearly everywhere.

In all, there are about 125 species of higher plants. The grasses are numerous (22 species). The time of first flowering is compressed into four weeks in the case of most plants. Indeed, a quarter of the species flower within the six-day period between June 28 and July 3. The whole vegetational process has only three months within which to complete its cycle. Floristically Spitsbergen belongs to the European-Asiatic realm. In particular, the flora even of Prince Charles Foreland, with its 55 flowering plants and 20 mosses, is entirely free from American elements. The biogeographical division between the two halves of the Arctic Regions is thus sharply defined. Of the flowering plants 20 do not mature their seeds and must therefore have grown in a warmer climate in the not remote past, to which circumstance fossil finds also bear witness.

In contrast with plant life the bird life is divided rather according to whether the habitat is on the coast or inland. Three-quarters of the species are sea birds. Along the coasts they breed in summer in many thousands; in winter they migrate southward. There are geese, ducks, gulls, guillemots, terns, and divers. Each species has its own definite rock or rock shelf as a nesting place; for example, the highest shelf is occupied by the burgomaster gull (*Larus glaucus*). A. E. Nordenskiöld describes one of the most populous colonies of auks from the eastern side of Spitsbergen as follows: "Black cliffs, 800 to 1000 feet high here, for a stretch of about a mile and a half, rise perpendicularly out of the sea, inhabited by millions of auks which sit close packed together in all the clefts and crevices, and we were witnesses of the literal truth of the well-known statement that the air is darkened by the number of fowl flying out of such a fell when a gun is fired, without it being possible to distinguish any diminution in consequence in the number of those which sit still so quietly that some, which had made their nests, could be reached from the boat and taken with the hand. Where we rowed forward there were besides great flocks upon and between the ice seeking their food." As compared with these coastal colonies bird life in the interior is meager. Here the birds are gulls, geese, ptarmigans, and especially

snow buntings (*Plectrophenax nivalis*). The extent to which the form and structure of the land is a determinant in the bird life is frequently evident from the steep mountain walls, which are inaccessible to foxes and for this reason offer all the more favorable breeding places for the gulls. Their droppings create a marked luxuriance in the plant life of the rocks round about, and this in turn attracts reindeer.

The reindeer, which is much hunted, still roams in herds, particularly in the east, where it knows no fear of man; but it also occurs on the west coast, as in the wide, green Sassen Valley. The Arctic fox is rarer. Along the coasts, especially in the east, the polar bear, the "bailiff of Spitsbergen," is to be found. In addition to the uncontrolled hunting of recent decades, the use of poison has wrought special havoc in the animal world. This practice has now been forbidden by Norway.

Sea mammals are represented by the narwhal, the finback whale, and the blue whale; porpoises occur in schools. But the enormous numbers of seals and whales have been severely reduced by the hunting of centuries. The Greenland whale, which has now disappeared, and the walrus, now greatly reduced, were still present in large numbers when the Dutch and English whalers skirted the coasts of the archipelago soon after its discovery and all the other nations of Europe followed in their wake. English mail packets linked up the stations on the west coast as early as 1623; in some years more than two hundred vessels left Holland alone. In Smeerenburg (Blubber City) a regular whaling settlement of the Dutch arose in 1617 with dwelling houses and try works; but in 1671 Martens found the city almost in ruins. In the eighteenth century the whale fishery was forced to yield to sealing and to pelt hunting. These pursuits were taken up by the Russians, during the course of which they wintered not only on the west coast but also in the east, especially on Edge Island. However, in the nineteenth century even this sort of hunting decreased. In the seventies the cod fishery had migrated to Spitsbergen, but it flourished there only for a decade. Whaling was taken up again by Norwegian sailors as early as the beginning of the nineteenth century and then resumed at the beginning of the present century; in 1905, 600 whales were caught; in 1912, only 55; and since 1920 this industry has again ceased. Thus the yield and the modes of exploitation of the animal life vary greatly.

A new natural resource of Spitsbergen has now come to the fore, namely coal. Known to the whalers since 1610 and used by them occasionally, it was, however, first investigated by Swedish geologists several decades ago, and it has been systematically mined only for the last twenty years. In geological age this coal belongs to the Carboniferous, Jurassic, and Tertiary. In quantity, the Carboniferous beds stand foremost; in accessibility, the Tertiary. Nearly horizontal seams

of Tertiary coal extend from one fiord to another. It is of excellent quality despite its late origin and approximates true anthracite in appearance and chemical composition. At one place the total thickness of the seams is 11 meters. The mines that have so far been successful are all located in the Tertiary beds. Obstacles are created, to be sure, by the transportation difficulties, especially the short navigation period from June to September; but a decided advantage is furnished by nearness to the coast, ease of access, exploitation by means of galleries rather than shafts, and the supportable temperature. As this is below the freezing point the gallery walls are covered with ice crystals, making the mines appear white. Pure fresh air is easily supplied, and artificial ventilation is not necessary. There are also no difficulties as regards water or firedamp. The supply of accessible coal on the west coast is estimated at a minimum of nine billion tons. Exploitation began in 1905 on the northeastern side of Advent Bay by an English company from Sheffield and was extended mainly around the whole circuit of Ice Fiord and southward to Bell Sound. At present English, Norwegian, Swedish, and Dutch companies, fourteen in all, participate. The Norwegian mines are those most actively developed. The total yield of the mines was 4500 tons in 1910 and over 300,000 tons in 1922. Norway thus becomes more and more independent of English coal. In addition to coal, gypsum, asbestos, iron ore, and marble are found.

Thus, as a result of the harbor equipment, the cableways, the storehouses and dwellings, the stock of domestic animals, etc., a group of embryonic settlements has arisen along the shores of bays that twenty years ago still lay in magnificent repose and isolation—bays that were in the habit of temporarily awakening to a brief life only through the annual advent of tourist steamers. The settlement on the southwestern side of Advent Bay is called Longyear City after J. M. Longyear of Boston, Mass., who developed the mines at this point, and may be considered as the capital; it has a summer population of 400 people. In addition there are six other settlements, all on the west coast. The population of Spitsbergen numbered 1400 in the summer of 1923, and 1200 persons lived there during the winter of 1923-1924. Regular mail steamers and wireless stations link up the archipelago with the civilized world.

This recent development soon led to Spitsbergen conferences, which discussed mainly the protection of the fauna and flora, becoming increasingly jeopardized. At the same time the question of political suzerainty, which had been broached as far back as the seventeenth century among England, Holland, and Denmark, became more and more acute. Before and during the World War the publications on the subject show how the different nations were becoming mindful of their historical claims and how they were sub-

stantiating them. England had seized a larger area than the others. The claim of the Netherlands was based on her right of discovery and her inauguration of the whale fishery. Russia, too, could claim an interest in whaling. As to scientific investigation Sweden certainly was the most deserving. Through whaling and later through mining Norway had established herself there: that country also was the one most in need of coal. To Norway the Versailles Treaty powers awarded the group in 1920, with the reservation that it was not to be fortified. The Powers (except Germany) have also the right to mine coal as well as to hunt, fish, and trade. At the time she took formal possession Norway reintroduced the old name Svalbard.

Bear Island

About 250 kilometers south of the southern point of Spitsbergen, Bear Island rises from the sea on the edge of the Barents Sea shelf in latitude 74½°; it is still within the influence of the storm paths of the North European Sea and hence is beaten by a heavy surf. The island is but a remnant of land that has been saved from abrasion; in structure it conforms entirely with Spitsbergen. Orographically it is divided into two parts. The northern two-thirds consists of a plain which from the 30-meter-high cliffed coast gradually rises to an elevation of 100 meters. Adjoining this abruptly is a high plateau, which falls off to the sea in vertical walls as much as 400 meters high and which culminates in an elevation of 536 meters. This southern part in basic structure exhibits the Caledonian folding of the Hecla Hook system. Discordant on this lies Devonian sandstone, which also occupies the larger part of the northern plain. The highest elevation in the south, Mt. Misery, is a tableland consisting of sediments higher in the stratigraphic scale: specifically, a steep-bordered layer of Upper Carboniferous (*Spirifer*) limestone and on it three peaks consisting of gently inclined Triassic strata. Evidently the limestone once covered the whole island and was in turn covered by Mesozoic strata. Marine abrasion then developed a level terrain in the north, whereas the more resistant dolomitic Hecla Hook block of the south more effectively withstood erosion. Scattered over the lowland are sharp-edged blocks of sandstone, and lakes lie in this lowland. There is no evidence along the coast of a late or postglacial uplift. Andersson interprets this to mean that between the two large uplifted areas, Spitsbergen and Fenno-Scandia, there is a region which was not uplifted. It seems to me, however, that it is also possible to assume that the traces were effaced on this storm-swept small island. The steepness of the shores, their rock needles and grottoes, bear witness to the continuing effect of heavy wave attack.

The island has no glaciers, but in Pleistocene times it was covered

by ice. It lies between warm and cold waters and has very changeable weather. Because of the drift ice it is cold in summer (July, 4.3° C.) and is almost constantly shrouded in fog. The soil, permeated with moisture, here becomes flowing soil, which is typically developed and which contributes to the levelness and softness of the landforms. The soil is generally bare and covered only by oases, as it were, of green moss, between which grow a few polar willows, whitlow grass, crowfoots, saxifrages, various grasses, and a few other plants, amounting in all to less than 50 species of phanerogams. The swampy and stony soil, the damp, foggy atmosphere, and the sparse vegetation impart a desolate aspect to the landscape. Only fulmars, guillemots, and the like fly in great flocks about the drab coastal cliffs, crying shrilly and alighting on the rocks that jut out from them.

The island has no good harbors and is surrounded by ice for half of the year. Although discovered by Barents as early as 1596, it is little visited and was not surveyed until 1898, by Swedish scientists. In past centuries it attracted to its waters whalers, who often killed hundreds of walruses in a few hours. Now the animal has disappeared. However, the island still has economic value because of its coal seams (Devonian); there are at least 200,000,000 tons available. The mines are the property of Norway, and the coking qualities of the coal enhance its value because it thus supplements Spitsbergen coal in the economic life of Norway. The population of the island amounted to 260 in the summer of 1923 and 82 in the winter of 1923–1924.

Franz Josef Land

In the same manner that Bear Island forms a bridgehead south of Spitsbergen a tenuous chain of islands leads over eastward to Franz Josef Land. Presumably there is a submarine ridge here and these islands lie on it. There are two, each about the same size as Bear Island and about equidistant from Spitsbergen and Franz Josef Land and from each other: White Island (Hvidöy, identical with Giles Land, discovered in 1707) and Victoria Island, discovered only in 1898 by whalers. The latter is 150 meters high and is completely covered by ice; this is also the case with the 250-meter-high White Island, so named after its ice cap. Their base has been determined to be gneiss and granite, as a consequence of which White Island takes its place as a further member in the series of Archean horsts of the northern border of Spitsbergen. Whether Victoria Island also belongs to the Archean base or exhibits the plateau structure of Franz Josef Land does not seem to be known.

Franz Josef Land itself consists of many islands lying close together which represent a greater stage of dismemberment than Spitsbergen. None of them approaches the size of Edge Island; many of them only

that of Bear Island. The area of the whole archipelago is about 20,000 square kilometers. It lies between latitudes 79° 45′ and 81° 50′ N., and between longitudes 42° and 65° E. Among all detached polar lands it thus lies farthest north and was consequently also the last to be discovered (excepting Northern Land), namely by Payer and Weyprecht in 1872–1874. The outlines as shown on the maps today are due to their surveys and to the later work of Leigh Smith in 1880–1882, Jackson in 1894–1897, Nansen in 1895–1896, Luigi Amedeo of Savoy in 1899–1900, Wellman in 1898–1899, Baldwin in 1901–1902, and Fiala in 1903–1905. The last four of those mentioned, as well as the Russian Sedov (1913–1914), all used the archipelago as a base for attempts on the pole, and Nansen landed here on returning from his polar sledge journey. This function as a base is characteristic of the islands because of their extreme northern position combined with relative ease of access as a consequence of their being reached by branches of the Gulf Stream in Barents Sea.

The archipelago is twice as long (east-west) as it is wide (north-south). Two transverse furrows, which have served as entrances for expeditions, divide it into three sections; these furrows are the deeper British Channel and the shallow and narrower Austria Sound. Between the two, in the middle section, lie most of the islands; they have a rather uniform medium size, with many small islands lying between, and as a unit are known as Zichy Land. The section east of Austria Sound consists of two somewhat larger islands, Wilczek Island and Graham Bell Island, in addition to a number of small ones. The third section, west of British Channel, contains the two largest islands of the archipelago, Alexandra Island and Prince George Island, with smaller islands. To these belongs also Northbrook Island, which forms one of the entrance pillars of British Channel, on which lies the celebrated, well-explored Cape Flora, a relatively friendly place with a green plain, frequented by birds, in front of the rock of the cape itself.

The islands consist practically throughout of plateaus lying under ice caps. These often leave exposed the steep coastal walls, individual capes, or foreshore lowlands. The plateaus are rarely more than 300 meters in elevation; only in the southeast do they attain 800 meters. They are due to the prevalence of basalt sheets, and thus the archipelago is closely related to the southeastern zone of Spitsbergen, King Karl Land. The basalt is 100 and more meters thick—at Cape Flora 165 meters—and rests on marine Jurassic sediments, particularly *Macrocephalites* strata. Intercalated in the basalt are five or six plant-carrying strata, whose age is variously interpreted as dating from the Upper Jurassic to the Tertiary. Accordingly, the land developed from a shallow Jurassic sea and was later overspread with basalt; the volcanic sheets, which were at that time connected

with Spitsbergen and possibly with northern Europe, were separated and broken up only in relatively recent times. Finally, shore changes took place and as a result left forelands and terraces; these generally lie between sea level and an elevation of 30 meters, in places of over 120 meters, and occasionally can be traced even under the ice. The profiles of the shores that are free from ice are steep immediately below the basalt walls, but lower down they are more rounded, being covered with basalt débris and some vegetation. The clayey, sandy Jurassic sediments are soft in themselves and only because of being frozen acquire steep slopes and are able to carry the scarped border of the basalts.

The snow line lies at an elevation of 100 to 300 meters. The only large ice-free area is on Alexandra Island; this consists of an ice-free lowland strip about 100 kilometers long and 10 kilometers wide which is soldered to the island on the north. Except for a few capes most of the islands are completely covered with ice, particularly around Austria Sound, and therefore next to Greenland are the most polar in appearance. "A covering of dazzling whiteness is spread over everything. The rows of basaltic columns, rising tier above tier, stand out as if crystallized," thus reports Payer from a sledge journey. The outlines are accordingly not sharp and irregular, but simple, smooth, domelike. But the ice caps are not particularly thick, as may be seen from slight irregularities on their surfaces and also from rocks which occasionally break through. Their motion is too slight to be measured. The icebergs that they produce are few and do not attain the heights reported by Payer and Leigh Smith; they are hardly more than 20 to 25 meters high and as a rule are tabular in form.

The conditions are here favorable for glaciation to the extent that the land, which still lies at the edge of the North Atlantic barometric depression, can draw on this ample source of moisture and, on the other hand, has a very short summer because of its high latitude. The sun disappears from the middle of October to the end of February. East and west winds predominate, together with northwest and northeast winds, the east winds occurring during the long cold period, the west winds during the warmer period, whereas southerly winds are almost entirely lacking. This picture clearly reflects the location of the archipelago in the transitional zone between the Atlantic area of low pressure and the Arctic high. However, in detail and locally, the direction of the wind is greatly influenced by the complete intermixture of land and water. Wide fluctuations in atmospheric pressure occur within a short period. Storms are also not rare; the *Stella Polare* experienced one that lasted eight days. Fogs are frequent. The ice-free stretches seem markedly to face toward the north and west. Also, the west coasts often become ice-free and make navigation possible along British Channel for about a month, although not

always. The mean temperature of July lies between 0° and 2° C., and in 1896 as well as in 1914 there was not another month that had a mean above the freezing point. The lowest monthly mean that occurred during the many expeditions that wintered there almost always lay close to −30°, the absolute annual minimum between −40° and −46°. In winter the weather is very clear. The small amount of precipitation is distributed quite equally over all periods of the year. "The snow never fell in large flakes, as we see at home, but was granulated, and hardened by the wind as soon as it fell, so that walking over it left no trace. It was carried by the wind like the desert sand; under a light breeze it ran along the ground, but when the wind freshened, the level of the driven snow rose to the height of several feet, and if there was a violent storm, it was impossible to know if the snow which enveloped us fell from the sky or was carried by the fury of the tempest. The snow did not lie evenly on the ground, but was piled up against every obstacle; it filled the hollow places and did not stay on flat surfaces, which made it impossible to calculate how much had fallen" (Luigi Amedeo of Savoy).

Vegetation is relatively more developed on the western and southern coasts. Here many species of lichens and mosses form mats. In addition there are only two dozen phanerogams. Among these saxifrages (six species), a number of grasses, like *Alopecurus alpinus*, and two species of *Poa* are frequent; there are also the grass *Pleuropogon sabinii* and, furthermore, *Ranunculus nivalis*, *Papaver nudicaule*, *Draba alpina*, *Cerastium alpinum*. On the other hand, *Salix* and *Pedicularis* are lacking.

For animal life there is hardly any room on the land; especially there are no reindeer. The fauna consists rather, on the one hand, of marine animals like the polar bear and seal and occasionally the walrus and, on the other hand, of birds, of which Jackson counted twenty-one species. Among these are the two main birds of the central Arctic basin: *Fulmarus glacialis* and *Pagophila eburnea*.

Novaya Zemlya and Vaigach

In the same meridional zone as the eastern half of Franz Josef Land lies the long island wall of Novaya Zemlya (New Land) and Vaigach. The latter island is a small rectangle lying in latitude 70° N. and longitude 60° E. It is separated from the mainland by the narrow Yugor Strait and is washed on its northwestern side by the waters of the wide Kara Strait. Vaigach is continued by the arc of Novaya Zemlya, convex to the northwest and extending from 70½° to 77° N. Novaya Zemlya is a double island broken in two by the winding, half-kilometer-wide fiord strait called Matochkin Shar (Matthew Strait) in 73⅓° N. (Fig. 26). At this strait the island is

about 100 kilometers wide. Novaya Zemlya and Vaigach together are 1000 kilometers long; they cover 95,000 square kilometers.

Novaya Zemlya lies athwart the polar exit of Russia and is hardly farther from Archangel than from North Cape. Hence (except for the Northmen) Russians have taken the lead in its exploration,' both the earliest and the latest, whereas its nominal discovery by Western European peoples in their search for the Northeast Passage was only an intervening episode. Trade and hunting expeditions to the Urals and the Ob as well as the wealth of fish in the surrounding waters probably brought the maritime population of the White Sea region to these shores before the end of the Middle Ages. Stephen Burrough (1556) is the Western European discoverer; the first clear knowledge of its position and extent was brought by the notable voyages of Barents (1594–1597), during which the first wintering in the Polar Regions took place. More accurate surveys and investigations of the nature of the land were then due to the work of Russian expeditions, among which the circumnavigation by the fisherman Loshkin about 1760, the four years' voyages of Lütke in 1821–1824, and the six weeks' sojourn of von Baer in 1837 were the most important, after which there followed in the latter half of the nineteenth century mainly Norwegian and, later, Dutch expeditions. In recent times the island has been relatively little affected by polar exploration.

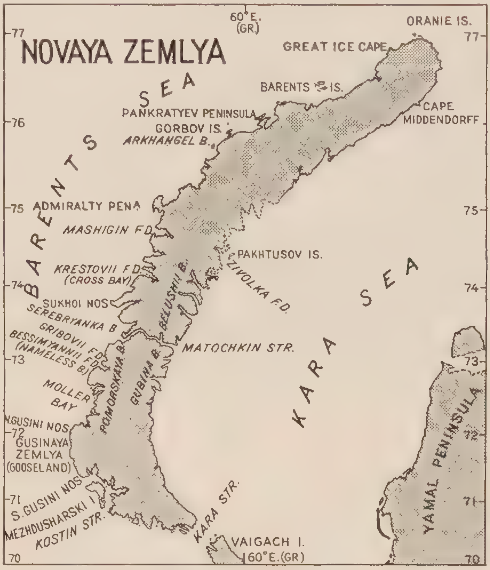


FIG. 22—Outline map of Novaya Zemlya. Mean scale, 1:12,000,000.

In structure southern Novaya Zemlya and Vaigach prove to be a continuation of a mainland axis, namely that of the Pai-Khoi, which branches off laterally from the northern end of the Urals. Certain gray limestones of Paleozoic age occur more or less in all three of these land segments as well as in the small island Dolgoi, which lies off to the side. They are heavily folded and on the southwest coast strike southeast-northwest. Northwards of the region south of Matochkin Shar folds corresponding in direction to the Urals and not to the Pai-Khoi set in with a north and north-northeast trend, bending to the east-northeast from 75½° on; mountain crests, coasts, and rocks are

substantially parallel in their strike. Holtedahl, who crossed the northern island in 1921 at Mashigin Fiord, here found the same folds and Paleozoic formations as at Matochkin Shar.

The mountains, at least in the south and middle, lie closer to the western side. The western coasts are for this reason steeper, rockier, higher, and more broken up. The land slopes off to the east; and on this side the coast is as a rule low, flat, and uniform and rises

FIG. 23—Looking westward along the southern side of Mashigin Fiord, western coast of Novaya Zemlya. (Photograph by R. Lund.)

to greater heights only near Matochkin Shar, in part rising in terraces to plateaus. In general rounded and flat forms prevail, as they do in the Pai-Khoi and Ural oldlands. However, the coastal indentations and the incised valleys, their steep slopes notched by melted-ice water above and buried in angular boulder talus below, break up the landforms to a considerable extent.

In view of the length and the narrowness of the land the coasts stand out as the most prominent element in the landscape. Along the whole western side there often lies in front of the steep flanks of the mountains a low foreland, which, however, like them consists of solid rock and, judging by the fossil shells found there, represents a Pleistocene abrasion surface. Still higher, narrow strand lines (Fig. 25) are also common in the east and west, rising at least to heights of 150 meters, possibly more. These forelands in part form prominent projections, such as the 100-kilometer-long Goose Land, Dry Headland (Sukhoi Nos), and Admiralty Peninsula, between which the coast often recedes in a large flat arc, such as in Kostin Shar, Moller Bay, and others. In addition to the last two forelands mentioned, the northern island also has an outpost in the Gorbovye (Hunchback) Islands. Here Pakhtusov was wrecked in 1835; the Admiralty Peninsula is the site of Wood's shipwreck in 1676. Back of these three outposts the western coast of the northern island presents a smooth

outline as a whole, in which, however, deeper bays occur, one of the largest being the narrow Cross Bay, which has also played a rôle in the history of the island. On the eastern side the general outline of the coast is more uniform than on the west. In its southern portion even detailed articulation is missing. Farther north, on both sides of Matochkin Shar, there is again greater indentation, but even here horizontal lines predominate in the relief as well as in the

FIG. 24—Ice cap about 500 meters above sea level north of the inner part of Mashigin Fiord. In the foreground the snow has melted, exposing the old dark ice. (Photograph by O. T. Grönlie.)

snow on the fiord slopes and thus, in spite of embayment, create the aspect of a uniform coast.

From south to north the differences in height, relief, and glaciation make possible a division of the land into three parts. The southern part up to about the middle of the southern island is, on the whole, low and flat. From the somewhat higher ridges of the western coast the land slopes off to plateaus generally less than 200 meters high, in the gentle undulations of which lie many lakes and rivers but no glaciers. From the northern end of Goose Land to beyond Admiralty Peninsula the whole land rises to greater heights; these reach nearly 1200 meters in the neighborhood of Matochkiń Shar. Deep, often ravine-like transverse valleys and fiords cut into it from both sides, and it is only an especially deep transverse depression that leads to a complete separation in the narrow Shar. Its depths vary in the manner of fiords, the greatest amounting to about 180 meters. Glaciers begin to appear in the valleys about Matochkin Shar, where the snow line probably lies at 600 meters. South of the strait the glaciers do not reach the western coast; only to the north of the strait, and especially from Cross Bay on, does the picture of the western coast with its crests and ridges and its glaciers debouching between them resemble the landscape of West Spitsbergen; however, the mountain peaks are not as sharp (Fig. 24). As one goes farther to the

north the ice surfaces in the interior become progressively wider. About abreast of Admiralty Peninsula glaciation has become so strong that inland ice appears. It constitutes the third major division of this island and rises to a height of 600 meters; the highest parts lie to the east. Along the northwest coast compact ice fronts many kilometers long and in places 40–50 meters high reach the sea between the even-topped black rock wall; among these is the much-praised Feodorovna Glacier. At the extreme northern end lies Great Ice Cape. Evidences of recession are noticeable everywhere: glacier fronts lie in places several kilometers behind their old moraines and are separated from them by lakes.

Novaya Zemlya rises like a wall between two seas. Barents Sea on the one side has wide and open communication with the North European Sea, from which it receives offshoots of the Gulf Stream. The Kara Sea on the other side forms a cul-de-sac of the West Siberian coastal sea and has fittingly been termed an ice cellar. As a consequence there is a contrast between the two sides of the island as to currents (see Fig. 11), driftwood, ice, climate, and life.

Along the Kara Sea side a weak current flows from the north and passes through Kara Strait to the western side, while under this current warm water penetrates into the Kara Sea. On the western side the current turns to the north and, like the water pressing forward with the Gulf Stream, flows along the western coast. The driftwood, which is mainly derived from the Siberian rivers, therefore collects much more on the eastern than on the western coast. Along the latter it decreases toward the north. The ice that is formed off the coast of western Siberia and in the rivers is caught by Novaya Zemlya as if by a breakwater and has little chance to drift away; also, the west wind is robbed of its force by the mountains so that it has little influence on the ice of the eastern side. Thus the eastern side is heavily barricaded, and its northern part was until very recently the only long stretch of coast that had not yet been surveyed. The western side is much freer of ice. This coast as far north as Cape Nassau can often be reached by vessels at a time when Kara Strait is completely closed. The western exit of Matochkin Shar can be open at times when the eastern end is closed. Generally the whole strait becomes navigable only at the end of July or the beginning of August. In August, 1907, along the western coast up to latitude 77° N. the *Belgica* met with water temperatures generally higher than 5° C., sometimes higher than 7°, whereas shortly before on the eastern side the temperatures had been between 0° and 2°.

The air temperatures conform to this difference. Not only is the whole western side several degrees warmer than the eastern side, but the western side in the latitude of Matochkin Shar has a warmer climate than the southernmost cape of the island, as this is open to eastern

FIG. 25

FIG. 26

FIG. 25—The innermost part of Bessimyannii Fiord (Nameless Bay), western coast of Novaya Zemlya (for location, see Fig. 22). Note the raised beaches on the fiord walls and the widespread delta deposits. (Photograph by R. Lund.)

FIG. 26—The middle part of Matochkin Shar, the channel dividing Novaya Zemlya into two islands. (Photograph by B. Lynge.)

influences through the Kara Sea—a condition analogous to those at the southern ends of Spitsbergen and Greenland. On the eastern side July with its temperature of 3.4° C. is as cold as latitudes ten degrees farther north in Northern Greenland. The mean temperature at Moller Bay is 6.2° in July and − 16.5° in February. The absolute annual minima are not less than those of Franz Josef Land: in Moller Bay − 39.6°, in the Kara Sea − 47.2°, in St. Phoka Bay even − 50.2° (1913) have been observed. Precipitation amounts to 300 millimeters in round numbers.

As in Spitsbergen, cold winds often break forth from the valley mouths on the western side, so that it is customary for boats in passing by to strike sail when opposite the valleys. Matochkin Shar has the same phenomenon in greater intensity; here, less boisterously but more continuously, the cold air flows through as an east wind from the ice-covered Kara Sea until the middle of summer. The two coasts often have contrasted weather: the damp days of one side are the clear days of the other, and vice versa, as Pakhtusov and Zivolka determined by comparing their diaries. Characteristic, too, are the rapid changes from clear to overcast weather, as well as the frequent dense fogs.

The slight summer warmth leads one to expect a sparse vegetation and a decrease in it from south to north. The vegetation is more scanty than that of Spitsbergen but similar to it and still more similar to that of Russia. On the southern island Holtedahl found 150 flowering plants but in the north far fewer. The plant cover is generally quite discontinuous even when it consists of mosses and lichens. The mountains of the west coast rise bare behind the dull green forelands. Among the thin lichen crusts that cover the rock blocks only an occasional Alpine poppy or other rock plant appears. Where the talus is more weathered, *Dryas octopetala* forms a continuous surface, with saxifrages, whitlow grass, and others interspersed in it. Where clay soil collects and splits open in polygonal cracks, the moisture in the cracks attracts mosses; and these in turn harbor other plants, such as *Eriophorum* and even *Salix polaris*. Limestone soils and animal droppings also make for a somewhat richer vegetation. At the foot of the mountains, finally, and in depressions there may be a denser covering; and a carpet of flowers may spread out consisting of yellow crowfoots, blue Jacob's ladders, purple saxifrages, and varicolored Arctic poppies. The rare grass *Pleuropogon sabinii* is also to be met with here. On the whole, the coastal area exhibits more abundant forms of life than the interior, and the vegetation there furnishes a still considerable addition to animal food.

Animal life also prefers the coasts and still more the sea. Immense colonies of guillemots and auks (*Uria troile*, *Alca torda*) occupy the coastal rocks with their "bazaars," as the bird breeding places here

are called. There are also petrels and gulls, particularly the dominant burgomaster gull. Bird life is richer in species and individuals on the side of Barents Sea than on the Kara Sea side. They all find their food in the sea. The fauna of the Kara Sea is by no means scant. Both seas, indeed, abound in crabs and fishes as well as in sea mammals, particularly seals, which have been for centuries the booty of the Russian and Norwegian coastal population, and in white whales (beluga, *Delphinopterus leucas*), which could be exploited commer-

FIG. 27—The Samoyed colonists at Pomorskaya Bay, western end of Matochkin Shar. The settlement's church in the background. (Photograph by R. Lund.)

cially, their oil and skin being suitable for the manufacture of a butter substitute and leather respectively. On land the native bird species include ptarmigans, snowy owls, snow buntings, as well as hawks, geese, and ducks in great numbers in the lowlands. Among land mammals the Arctic fox and lemming are numerous, whereas the polar bear and reindeer, because of being hunted, are now restricted rather to the eastern coast. The inland waters contain many fish, particularly species of salmon, which are of economic importance. There are quite a number of insect species, too; but birds remain the dominant form of life. They and the scant floral carpet make up the charm of the brief spring.

Novaya Zemlya is a hunting colony, hunting and trapping being maintained from Russia as a seasonal occupation. Samoyeds as well as Russians go there every year. The former go in groups to hunt reindeer or to secure pelts, which then are taken by traders to the Russian markets. The farthest small post of the fur traders lies on the mainland side of Yugor Strait; this place, called Khabarovo, has also become known as a halting place of expeditions. Since the seventies four permanent settlements of Samoyed families (Fig. 27) have gradually been established, and under the protection and admin-

istration of the Russian government they carry on bear hunting and fishing. They number over one hundred persons. All these settlements lie on the west coast; indeed, the whole economic life unfolds itself on the western side. Hither in the spring come Russian and Norwegian vessels to hunt fur animals, to catch salmon, to collect eider down, and, mainly, to fish. Occasionally the ships winter here. Numerous crosses with inscriptions are to be found at points on the coast and bear witness to the presence of such hunting parties and occasionally to their shipwreck. The economic yield varies greatly according to years and periods, and the number of those who frequent these shores varies correspondingly. Toward improvement, especially in the sea fisheries, systematic exploration can still contribute much.

Other possibilities for development exist in the domain of mining: a number of Russian expeditions have been active in this field—three in 1911 alone. Anthracite coal and copper, for example, are to be found there.

Vaigach

This small island to the south can be grouped with Novaya Zemlya, as was done above. On the other hand, it is also closely related to the mainland. Not only the narrowness of the shallow Yugor Strait (3 kilometers) and the shape and direction of its coasts but also its uniformly low relief (generally much below 100 meters) and its continuous tundra make it evident that it is a closely connected part of the Pai-Khoi. Slate and limestone compose the lower ridges, which with their northwest strike correspond completely with its structural direction. The strata are almost vertical and thereby also give direction to its coasts and higher elevations. In the lowlands lie massive recent marine sediments interspersed with lakes, and everywhere traces are visible of the very recent uplift of the island and of its having been subjected to the influences of floating ice. The flora on the lowland soils is different from that on the rock surfaces. It is poor in species but luxurious in growth; foot-high flowering plants, grasses, rushes of the family Juncaceae, together with mosses and other plants cover large surfaces in dense stands. Willows attain the height of half a meter. Swarms of those Arctic demons, the mosquitoes, are not lacking.

The Samoyeds make use of the grassy plains as good reindeer pasture and of the rivers and estuaries for catching fish, seals, and whales. Some of the Samoyeds remain here during the winter, especially on Kara Strait, where the climate is milder, because of the more open sea, than on Yugor Strait. Yugor Strait can be crossed in winter on sleds; Kara Strait, however, can not.

The Pai-Khoi and the Polar Urals

The longitudinal coasts of Vaigach Island are continued so directly in those of the projection of the mainland on the other side of Yugor Strait that the island is hardly separately distinguishable on small-scale maps. The same unity marks the internal structure; the backbone of Vaigach reappears on the mainland in the low plateau-like ridge of the Pai-Khoi (which means rock ridge), parallel to which is the axis of Kara Bay (Baidarata Bay). This direction impinges almost at right angles on that of the Urals at their northern end. But between the Pai-Khoi and the Urals lies the deeply incised valley of the Kara River, which flows along the Pai-Khoi across the hilly tundra to Kara Bay. In its broad valley bottom it furnishes good reindeer pasture.

Northward from about the Arctic Circle the Urals are called the Samoyed Urals, and the name serves to mark them as a separate entity of Arctic character. The Urals are here a crystalline ridge with marginal belts of Paleozoic rock and with the rounded forms of glaciation only partially obliterated by postglacial erosion and solifluction. The main ridge is an undulating surface only about 500 meters high, surmounted by individual elevations that attain 1000 meters or more. The outer belts are more highly articulated and dissected. There is no glaciation today. Trees in the form of deciduous forests, although only in open stands, extend almost to latitude 68° N., particularly on the eastern slope. At the foot of the mountains tundra extends widely—damp, dry, and stony by turns—interspersed with lakes and swamps. In contrast with the uninhabited mountains, which are covered with snow late into the summer, the tundra is overrun by Samoyeds, Zyryans, and Ostyaks with their reindeer herds. Passes lead from the Pechora by way of its tributary, the Usa, to the Ob. At this point, therefore, the problem of water communication with the Ob had led to investigations as early as the first half of the last century.

The Arctic Fringe of the European Mainland

In northeastern Europe the Polar Regions begin almost exactly on the Arctic Circle. The forest limit weaves in and out along this line. Even west of the White Sea the narrow belt of the Murman Coast is polar, being tundra; to the east the tundra widens, takes in all of Kanin Peninsula, encircles Cheshskaya Bay, and continues to increase in width up to the Polar Urals. The limit thus defined has no connection with the geological structure. In structure the marginal polar areas are rather parts of the great North Russian Plain. This plain begins at the North Russian height of land, which extends as a low rise averaging 200 meters in elevation from the Urals along the 60th parallel to the Valdai Hills and forms the divide be-

tween the Caspian Sea and Barents Sea. At the same place near the Urals there diverges the Timan Ridge, which reaches an elevation of 300 meters; this is an almost completely base-leveled folded mountain system that can be traced in a north-northwest direction to the tip of Kanin Peninsula and that divides the North Russian Plain into two parts, the Pechora triangle and the Dvina quadrangle. The greater part of these low plains consists of Quaternary deposits, partly of glacial, partly of marine origin. Only in belts, particularly along the river courses and in the Timan Ridge, do the older basement rocks appear; on Kanin Peninsula the Archean core of the Timan oldland is uncovered. Near the coasts the lowland in certain sections rises moderately, as in the case of the Great Land Ridge between the mouth of the Pechora and the Urals.

The coasts themselves are flat about the Pechora and farther east; to the west of Timan Ridge they are mostly low cliff coasts. They are accompanied by coastal terraces, for example on the north shore of Kanin Peninsula at a height of 60 to 90 meters. The Pechora dominates the Pechora triangle with its long double-bend course, its many tributaries; its tangled delta, and the lagoon-like Pechora Bay and leaves enough room only for very short but broad and full coastal rivers. To the west no large river breaks through the tundra belt; Mezen, Dvina, and Onega all debouch in the forest. In the White Sea region only the two walls of its vestibule, Kanin and Kola Peninsulas, have a polar aspect. To be sure, the White Sea suffers a great deal from ice. That is what gave the more favorable Murman Coast its commercial importance—the fact that its harbors, thanks to an offshoot of the Gulf Stream drift, remain open all year. Archangel is ice-free only half the year, the Pechora mouth only a third of the year. Around the White Sea also there is no permanently frozen ground, whereas there is in the area between the Pechora and the Urals, which constitutes a vast tundra. Because of this frozen subsoil and the generally low elevation the ground here becomes very moist in summer and attracts swarms of mosquitoes.

Where the tundra begins there are patches of forest—called by the Russians *ostrova*, i. e. islands—whose trees belong to the same species but change their shape and height and become sparser and finally dwindle down to individual scattered outposts. A forest limit and a tree limit may thus be distinguished, according to R. Pohle, which lie about one to one and a half degrees of latitude apart. On Kanin the tree limit lies at 67° N., at the mouth of the Pechora at 68⅓°, and on the Urals at 68°. The mean 10° July isotherm also lies between the parallels of 67° and 68° in this whole belt. The marginal trees are firs and not, as in Siberia, deciduous trees. Along the lower Pechora the tundra is especially flat and damp and consists of sphagnum moss.

Commerce on the tundra is concentrated along its southern border. Here ran an old trade route which was once used much more extensively than now, as at the end of the Middle Ages and later still in the seventeenth century. Along it pelts were conveyed from the east and then were carried southward from Mezen. This town was at that time an important trade center on the Russian polar marginal belt. The felling of trees for the use of the tundra caravans caused a retreat of the tree limit, for in such zones of unstable equilibrium every forest island that is laid low has a hard struggle to regain a foothold against the luxuriant tundra vegetation and the wind. In addition, the recession of the forest has a natural cause in the gradual formation of peat on the forest floor as a consequence of the advance of the tundra plant association.

The east-west traffic of this marginal belt also made use of a natural line of water communication: the boats sailing from Mezen up the Peza reached the Tsilma over a *volok* (portage), thence went down this river to the Pechora and up the latter and the Usa to the Urals and even across these mountains to the Ob. Today steamboats ply on the Pechora. Another means of communication in the past as well as today were the long sleds of the tundra nomads. Even in summer (Fig. 28) they glide like canoes, easily and with a swaying motion, over the shallow pools and peat swells of the swampy ground. Pulled by a reindeer they can easily cover 100 kilometers a day.

Seasonal migration governs the wandering of the nomads over the tundra. In the spring they go to the coasts in order to protect their herds from the mosquitoes. In winter they stay near the forest limit in order to pasture their flocks on the lichens of the tundra, to hunt fur animals in the forest, and at the same time to seek protection from the snowstorms of the open country.

Communication with the Arctic Sea was maintained by the Russians predominantly by way of the Dvina, which flows entirely within the forest belt. As early as the twelfth century the Russians had reached the White Sea along this excellent waterway, which had previously been followed by the Northmen in the opposite direction, and thereby attained the gateway to the Arctic seas with their abundance of fish (cod). Here they became proficient in maritime affairs and established contact in the sixteenth century with English and Dutch sea trade, with which the foundation of the harbor of Archangel was associated. In the whole adjacent region the Russians have gradually absorbed the Finnic peoples in their concentration of the population in towns; they have also established a fairly continuous zone of settlement along the adjoining coastal belt as far as Kanin Peninsula, while the tundra has only a few settlements here and there, most of them along the rivers. Those to whom the tundra is the main field of economic activity, however, are the Samoyeds.

To the south of them in the forest live the Zyryans. The Samoyeds are for the most part still polar nomads. West of the Urals they are about 7000 in number. They hunt, fish, and breed reindeer and are exploited by the enterprising Zyryans. The Lapps of Kola Peninsula are not reindeer breeders. They fish in summer and in winter are sedentary, like the Russians. In addition there are Norwegians and Finns on the coast. Just as in the case of the Zyryans and the Samoyeds, so the Finns crowd the Lapps towards the sea.

Kolguev Island

Kolguev is the only large island off the stretch of coast just discussed. It lies between Kanin Peninsula and Novaya Zemlya, nearer to the mainland than to Novaya Zemlya. It is of the same structure as the coastal belt, a block of sand and silt deposits that lies in shallow water and that evidently has risen from the sea only in the geological present. Its highest sand hill reaches an elevation of 75 meters. The whole fauna and flora of the island must have been transported over the sea. Among them the most conspicuous are three species of fresh-water mussels. The icy storms and fogs as well as the low summer temperature make its plant cover sparser and more Arctic than that of the mainland. Its tundra is interspersed much less frequently with woody growths, and in many places weather-resistant lichens even take the place of mosses. On the western side the flora is more abundant and blossoms sooner because that side is more free from ice. In summer the island is literally covered with geese and swans, which are often shot in great numbers by the Samoyeds in the service of the Russian traders. The Samoyeds hunt fur animals and occasionally spend the winter here, without, however, having a permanent habitation.

The Siberian Arctic Zone

The Zone As a Whole

East of the Urals the Arctic zone of the mainland gradually increases in continental characteristics and in nearness to the pole. While the latitude of Yugor Strait is 70°, the Samoyed Peninsula extends northward to 73° and the Taimyr Peninsula to 77½°. Beyond the Taimyr Peninsula the Arctic coast recedes again, at first rapidly and then, from Khatanga Bay on, gradually, until in the Chukchi Peninsula it lies below 70° and in Bering Strait even below the Arctic Circle. Accordingly, the Arctic fringe increases in width from the Urals to the Taimyr Peninsula and decreases from there eastward. The 10° July isotherm, which, we have seen (p. 110 and Fig. 4), furnishes an important criterion for setting off the Arctic Regions, goes through the heads of practically all the bays, except the Ob-

Taz Gulf, which it bisects; it connects, namely, the upper ends of Baidarata Bay, Yenisei Bay, Khatanga Bay, Borkhaya Bay, and Kolyma Bay and then swings off to the south to include the broad northeastern corner of Asia and Bering Sea. Thus the land projections, especially Taimyr Peninsula and the offshore islands, have Arctic characteristics. The tundra limit, which is another important delimiting factor, does not coincide completely with the temperature line. On the whole it lies farther south and thus widens the Arctic zone. On the other hand, the rivers make breaches in the tundra and as a rule carry the forests to the river mouths, i. e. to the 10° July isotherm, or even beyond. Throughout the belt, forest and tundra interdigitate.

The most prominent land projections are the Samoyed Peninsula and the Taimyr Peninsula as well as the continuation of the latter in Northern Land. Between the Ob and the Yenisei there lies Gydanski Peninsula. East of the Khatanga there follows the protrusion of the Lena delta; and between the Yana and the Indigirka is a convexity of the mainland which is continued in the New Siberian Islands. Off the Chukchi Peninsula lie Wrangel Island and Herald Island. The projections that extend out farthest were glaciated in the Pleistocene. On the west as far as the Yenisei there are pronounced lowlands consisting generally of Pleistocene marine sediments; in the Taimyr Peninsula the lowlands are on the whole higher and are crossed by a ridge of moderate height; still higher and mainly consisting of hard rocks are the topographic elements east of the Lena.

A monsoon-like change in the direction of the wind characterizes the whole Asiatic Arctic zone: in winter winds from off the land predominate; in summer, winds from the sea. For this reason the coastal plains have the characteristic cool polar summer (Sagastyr, 4.6° C. in July), whereas a short distance inland the July means may exceed 10° (Nizhne Kolymsk, 12.3°). The winter cold, on the other hand, is almost the same at both places (−37° to −38° in the coldest month); while farther inland it increases appreciably. The winter is more constant than in the European Arctic regions because there is less intrusion of warm cyclonic spells. To be sure, off the whole coast there are stretches of open water, *polynyas;* occasionally when the wind blows over these onto the land it brings fine, needle-like frozen vapor, or frost smoke, but it brings little warmth. In the summer, on the other hand, the raw wind from the ice will destroy green vegetation and flowers for some distance inland from the coast.

The whole zone derives its character and geographical limits mainly from the tundra. The tundra varies greatly according to latitude, subsoil, landforms, and ground-water level. At the western end the moist flat tundra predominates, the so-called "quaking bogs," made up mainly of sphagnum mosses that turn into peat

below. Lakes are interspersed whose shores are bordered by meadow-forming reed grasses (*Carex*) and cotton grasses (*Eriophorum*). In the undulating and higher land of the Taimyr Peninsula and farther east the tundra becomes drier, and this permits the types of mosses that cover the ground sporadically, such as the haircap moss (*Polytrichum*), or the still more xerophylous lichens, such as the reindeer lichen (*Cladonia*), to become the dominant plants. Completely dry, "stony" tundra is not rare on the Taimyr and Chukchi Peninsulas. The trees that push out into the tundra belt are rather deciduous than evergreen. Among the latter there are the dwarf juniper and larches; among the former, birches, alders, and willows. The willow bushes afford fuel for the nomads far into the tundra; where they disappear man disappears. The willow is an outpost of the forest zone; it is generally dwarfed to a height of a meter; the trees are wind-clipped, their trunks lying prone on the ground and their branches stretching far out. In addition, there are berry shrubs, such as the crowberry, the whortleberry, the cloudberry. These interspersed plants with their many-colored flowers and their bright autumnal foliage impart color to the tundra—but only in spots. The dominating vegetation gives it a dull and hopeless aspect.

The characteristic animals of the Siberian tundra are mainly the lemming, the Arctic fox, the ptarmigan, the snowy owl, and, along its southern border, the reindeer, and on the coast and the islands, the polar bear. Of amphibious animals there are few; likewise of insects, except for the swarms of mosquitoes in the summer. Bird rocks appear only exceptionally.

The human inhabitants throughout the region stay away from the offshore archipelagoes. The mainland zone is likewise uninhabited in its northernmost projection, the Taimyr Peninsula. Where the zone is inhabited the density is expressed in hundredths per square kilometer. The inhabited area is divided among a number of nomadic tribes, among which the Samoyeds, whose domain reaches over into Europe, and the Chukchis are the most purely representative of Arctic nomadism, whereas the others are only offshoots of peoples living farther south in Siberia. They all show Mongolian racial characteristics to a high degree. Their most general basis of living is the reindeer, which is bred by most of them; to this is added the abundant fish of the estuaries and seas. For vegetable food there are berries and fruits in great quantities, as well as the roots and stems of angelica (*Archangelica officinalis*).

The Samoyed, or Yamal, Peninsula

Yamal (i. e. "end of the earth") Peninsula is about 600 kilometers long and averages 180 kilometers in width; it extends exactly

north and south and is bisected by the 70th parallel. It has a low, sandy surface recently built up by the Ob, uplifted from the sea as indicated by terraces, and overspread with tundra cover. Where this cover is lacking the sand has often been built up into dunes. A low divide, not over 100 meters high, extends lengthwise. From both coasts short brooks have eroded their young valleys and approach each other in their sources. It was thus possible in the sixteenth century for Novgorod seamen to carry on an active fur trade across the peninsula and recently for the Soviet Government to plan a canal to avoid its difficult circumnavigation. On the western coast of the peninsula the sea is relatively free from ice even for weeks in winter. In the interior there are a great many shallow lakes which white whales and seals can enter from the sea. A small lake in the center is deemed extremely sacred. The "mountain ridges" of the natives and the Russians are only the somewhat higher parts of the tundra between the depressions occupied by lakes and swamps. In its northern third the peninsula becomes lower, to end in a shore a few meters high.

As a result of its long north-south extent the peninsula clearly displays a gradation of its life forms. Willows and birches are scant in the north, more abundant in the middle, as is also grass; in the south there are alder bushes and firs. The bird and mammalian fauna also increases towards the south; the hare occurs only in the south, the polar bear only in the north. In the southern and central parts the Samoyeds can pasture their reindeer the whole year through and can fish in the lakes in the summer. They go towards the north in the spring for bear and seal hunting. Some spend the winter there, but the majority return to the south in the autumn. Here trade at Obdorsk is an attraction. The Samoyeds are the only inhabitants of the peninsula. They are the largest reindeer owners. There are about 1000 people and over 100,000 reindeer. In the surrounding tundra the Samoyeds are intermingled with Ostyaks and Zyryans.

The Peninsulas Between the Ob and the Yenisei

These peninsulas, a nameless smaller one between the Ob and the Taz and a larger one between the Taz-Ob and the Yenisei known as Gydanski Peninsula, are not so individualized geographically nor so important from the standpoint of settlement and commerce. On the whole they are, however, similar in structure, surface cover climate, and life to the Samoyed Peninsula. The coasts are higher, in places namely 30–40 meters high. Along the Yenisei there are many fishing villages. In addition to the nomadic tribes already named there are the Yenisei Yuraks. The right bank of the river is steep; the left, flat and occupied by sand banks, mud banks, and low

islands. These are flooded in the spring by the warmer river water, thawed out, and covered with a thin fertile coating of mud which favors the growth of meadow grasses and willow bushes. These river lowlands could feed many herds. They thus represent oases of higher vegetation in the tundra belt. More southerly plants also, such as foxglove, are transplanted into the tundra area by the Yenisei, as is done by the Siberian rivers in general along their banks.

Taimyr Peninsula

Between the Yenisei and the Khatanga the Taimyr Peninsula projects with a broad front and carries the northernmost point of the continent, Cape Chelyuskin in latitude 77° 43′ N., which was first passed, on dog sledges, by Chelyuskin, mate in the party of the Great Northern Expedition (see p. 101) commanded by Khariton Laptev. The land is not as uniform as it is to the west of the Yenisei, a slight modulation of the relief creating variety in the landforms and the character of the tundra. Two north-flowing rivers, the Taimyr and the Pyasina, divide the peninsula into three parts and in narrow valleys break through the Byrranga Ridge. This ridge, narrow and low, crosses the peninsula like a backbone for a distance of nearly 1000 kilometers. Consisting mainly of Paleozoic rocks, it seems to be a detached northern end piece of the Urals, although another view interprets it as part of an old folded zone on the western border of the Central Siberian Plateau. The Byrranga Ridge rises to a height of over 300 meters, in part precipitously. The coast also is often steep and with its low, rocky skerries is a hard stretch to navigate. The largest group of skerries are the Nordenskiöld Islands off Taimyr Bay. Far out stands the rock pillar of Lonely Island in 77½° N. and 86° E. In several localities gneiss, granite, and crystalline slates appear. Of younger rocks there are especially diabase and dark clay slates, seemingly Triassic. These coastal rocks, also, give evidence of having been folded, but in different directions. A flat shore with driftwood that has been carried far inland, as well as river terraces and marine shells, indicate that transgression has taken place and that slow uplift still continues. The driftwood is of value to the Samoyeds on their summer migrations. In the skerries and fiords of the coast, as well as on the mountains inland, rounded glacial forms predominate as a rule. Both to the north and to the south of the Byrranga Ridge the landscape is morainic, with numerous erratic blocks.

The greater elevation of the land combined with the higher latitude leads to a different development of tundra. The ground is drier because of the water flowing off more easily and because of the winter winds; thus there predominates the dry high tundra (Fig. 28),

in which mosses of the genus *Polytrichum* take the lead instead of sphagnum. Creeping willows are interspersed; the resistant genus *Salix polaris* is here the most northerly woody growth. There are more lichens, particularly the reindeer lichen; they flourish on the poorest rocky and gravelly ground. In places there are bare spots of rocky or loamy-sandy and gravelly soil. Even the plant-covered areas do not differ much in color from these bare spots: the moss patches are a

FIG. 28—Summer sledging in the dry tundra of the Taimyr Peninsula near Golchikha on the right bank of the Yenisei estuary. The soft carpet of the moss tundra affords almost as good a surface in summer for sledging as does its snow cover in winter. (Photograph from H. U. Hall.)

dirty yellow-brown, the lichen covers are gray, and hardly of a different color are the scanty grasses that have been subjected to the summer heat and wind. "Colorless, dull, and dispiriting," according to Middendorff, is the view across the tundra. This rock tundra lies to the north of the ridge. The picture is brighter in the depressions, where moist ground permits a continuous grass cover, interspersed with herbs, berries, and woody bushes, as is the case to the south of the ridge. The forest extends farthest along the southeastern flank of the peninsula; here, near the mouth of the Khatanga, lies the northernmost forest of the earth, consisting of larches, in latitude 72° 50′ N.

The temperature at the southern edge of the Taimyr Peninsula can sink below the freezing point even in the warmest month, which averages about 10° C. The snow is often driven in very severe blizzards, called *purgas*, over the bare, far-stretching surface. Many

travelers, such as Tretyakov, Middendorff, and others, give vivid descriptions of these storms, the former in Russian in the following terms (according to Arved Schultz): "The *purga* is no snowstorm, no *buran*. These snowstorms are only, as it were, preliminaries to the *purga;* the natives pay no attention to them and drive out on the tundra without further ado. But when the real *purga* sets in, i. e. when hard, dustlike snow whirls over the land and in the air, when this snow dust fills one's eyes, stops one's breathing, penetrates into the deepest folds of one's clothes, and throws down man and beast, when 'the *purga* thunders,' when 'the dark *purga* has begun'—then all seek protection and safety. The native ties his animals with thongs and lies down with his head against the wind; his animals do the same. Thus they lie often one, two, yes even four days without food. From time to time, nevertheless, they try to change their place in order to let the reindeer find something to eat. With slight interruption the *purga* may continue as long as twelve days. When it is over there are generally wonderful northern lights."

The inhabitants in the western part of the peninsula are Samoyeds; in the eastern, Tunguses. In summer they advance with their herds along the whole line to the Byrranga Ridge. In winter they retreat to the forest limit, to the Khatanga, to the source of the Pyasina, and even to the Yenisei. That the wide northern spaces of the land are entirely uninhabited may seem surprising. Middendorff ascribes it to the lack of good pasture in the rocky tundra, von Toll to the insufficient amount of driftwood. Fossil driftwood does not seem to be present in sufficient quantities, and the large rivers which come through the forest area, the true purveyors of driftwood, are entirely lacking in the land.

Northern Land (Severnaya Zemlya), Formerly Nicholas II Land

In 1913, on the third voyage of the Russian ice-breakers *Taimyr* and *Vaigach* under Captain Vilkitski, new land was discovered in latitude 80° N. and longitude 100° E., i. e. north of that Cape Chelyuskin that had already been reached by the Great Northern Expedition (1734–1743) and had been circumnavigated later by Nordenskiöld, Nansen, and Toll. Therefore it was hardly thought possible that land lay near by. The new discoveries consist of two small islands 50 kilometers north of the cape, Little Taimyr Island (formerly Tsesarevich Alexis Island) and Starokadomski Island, and, adjoining them on the northwest, Northern Land proper. Its eastern coast was followed past a deep embayment in 79⅓° N. until it turned west in 81° N. The coast ends in cliffs more than 500 meters high (Fig. 29), between which glaciers descend. Presumably the axis of Northern

Land represents the continuation of the Byrranga Ridge and other lines of hills in the Taimyr Peninsula, because thence the belt of Paleozoic rocks (p. 170) bends noticeably northwards into the Chelyuskin Peninsula, the northernmost projection of the Taimyr Peninsula, leading over to Northern Land. Thus the Kara Sea is hemmed in still more in the northeast, and its heavy ice conditions become more comprehensible. The new land proved to be inhabited by reindeer, lemmings, polar bears, and birds.

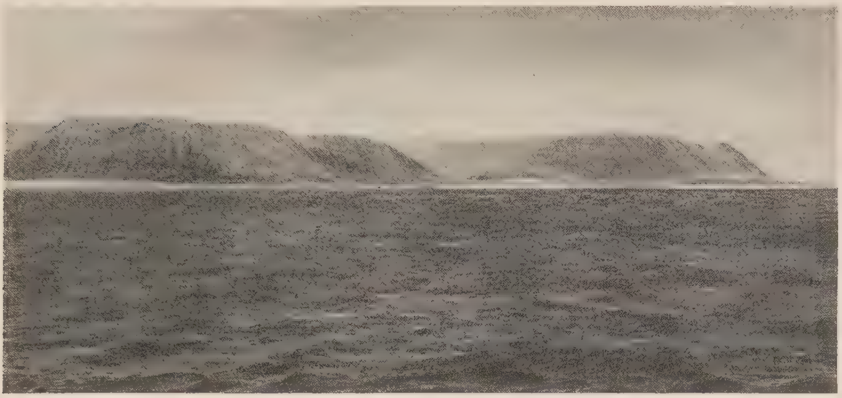


Fig. 29—The east coast of Northern Land. (Photograph from N. A. Transehe.)

The Coastal Belt Between the Taimyr and Chukchi Peninsulas

Between the eastern end of the Taimyr Peninsula and Svyatoi Nos (Holy Cape, 141° E.) the Arctic Sea forms a marked reëntrant in the continental land mass. This embayment is accentuated by the New Siberian Islands, which form its eastern side. Being thus clearly defined, it has a special name, Nordenskiöld Sea (or Laptev Sea). The coast of this sea is divided into two about equal parts by the projection of the Lena delta. In the western part only a narrow fringe of land partakes of the polar character of the Taimyr Peninsula. A line drawn from the head of the Khatanga estuary to the apex of the Lena delta outlines a coastal strip that still belongs to the tundra. Its surface is about 100 meters high, level or slightly interrupted by rock ridges, ending in a steep coast and a foreshore consisting of Mesozoic sediments interrupted here and there by basalt and diabase. The tundra is here of the same dry type as in the Taimyr Peninsula region. It is sparsely inhabited in the west by Yakuts, in the east towards the Lena by Tunguses. At the river mouths lie fishing villages.

The mouth of the Lena occupies almost exactly the middle of the whole Arctic coast of Siberia. The mean annual temperature here

is the lowest in that belt—less than $-17°$ C. The winter cold, however, is made milder by the sea; and as the summer temperature is reduced by it, the extremes are modified. Inland these extremes are heightened, and Verkhoyansk, with a January mean of $-50.5°$ C., represents the pole of coldness in the northern hemisphere. In this cold breathing becomes painful; and the exhaled vapor crystallizes to crackling needles of ice. Parties on the march are enveloped in a thick cloud of fog. Ice forms in the nostrils of the horses and threatens to suffocate them. The ice in the East Siberian rivers attains a thickness of 2 meters, that in the Indigirka River at its mouth even of 2¼ meters; in the Yenisei, on the other hand, it remains less than 1 meter. The mean July temperature at Verkhoyansk, however, is high, amounting to 15.4°; this makes it possible here at the pole of coldness for vegetables to grow and for forests to exist on permanently frozen ground.

In keeping with these conditions the mouth of the Lena in January has a temperature 14° higher, in July 11° lower, than the pole of coldness. Nevertheless, because of the strong winds the winter cold at the mouth of the Lena is hardly more agreeable to bear than the much colder but calmer air of Verkhoyansk. In summer the cool wind from the coast, to be sure, keeps away the mosquitoes from the northern part of the delta, but otherwise the summer there has little that is attractive. "Almost constant strong wind disturbs all observation, the eyes water, the fine sand is driven by the wind painfully into one's face, light objects are wrenched from one's hands . . . About the middle of July it becomes quiet on the tundra, that is to say, one sees no birds. All are either breeding or molting; only gulls and, rarely, a flock of *Sommateria spectabilis* are to be seen" (Bunge).

In the southern part of the delta begins the forest, which has been advanced thus far northward by the river. Immediately above the delta the flora, which is of sub-Arctic character, is considerably diversified; between 71° and 72° Andersson in a few months collected four hundred species of phanerogams and cryptogams.

The delta is still within the inhabited zone; its western part is occupied by Tunguses, its eastern by Yakuts. The inhabitants have no reindeer and hence no skin tents. Instead they have firm *yurts* made of driftwood; large numbers of these huts are scattered over the plain and are used on hunting trips. What Obdorsk means as a trading center to the Samoyeds of the Yamal Peninsula, Bulun, a small upstream settlement on the Lena, is to these delta dwellers. Furs and mammoth tusks are here articles of trade.

To the east of the Lena as far as the Chukchi Peninsula the coast is steep, of slight elevation, with a sandy foreshore and shallow coastal water interrupted by the estuaries and delta plains of coastal rivers. Immediately east of the Lena two wider bays, Borkhaya

Bay and Yana Bay, are separated from each other by the triangular sandy headland of Cape Borkhaya; and farther to the east the Indigirka and Kolyma debouch into two larger embayments of the coast, in front of the easterly of which lies the group of the Bear Islands. From the mouth of the Kolyma to Chaun Bay the coastal development is of the ria type. The interior is occupied by considerable elevations. Ranges such as the fault-block Verkhoyansk Mountains, which form the western scarp border of the East Siberian

FIG. 30—Low tundra shore at Kolyuchin Bay, Chukchi Peninsula. (Photograph from N. A. Transehe.)

Plateau, and their spurs here reach the coast (Khara-ulakh Mountains east of the Lena). Conical and tabular mountains of Mesozoic basalts, attaining elevations of more than 400 meters, stand on Svyatoi Nos, with which cape the continent stretches out towards the New Siberian Islands.

This relatively elevated position of the land gives it the character of a dry tundra in which mountain and coastal tundra merge. In places it abounds in small lakes and is crossed by many short coastal rivers as well as by the three major rivers and their tributaries. In their valley depressions moist tundra sets in, unless, as is the case in some of these valleys, forest, consisting of larches, birches, and aspens, extends out to the coast. Arved Schultz calls this formation in the polar belt of Eastern Siberia "mountain forest tundra." Thus there is more protection and more possibility of economic development here than in the flat and open tundra of the west; "and the relatively large number of small fishing villages along the lower courses of the rivers makes these regions appear less isolated than the tundra region of central Siberia." Fishing by the natives is carried on along most of the coast from the mouth of the Lena to Bering Strait, whereas west of the Lena it is hardly carried on at all. The inhabitants as far as the Indigirka are mostly Yakuts; from there to the Kolyma, Yukagirs; and thence to Bering Strait, Chukchis.

FIG. 31

FIG. 32

FIG. 31—Cape Dezhnev (East Cape). FIG. 32—Chukchi settlement at Cape Dezhnev. (Photographs from N. A. Transehe.)

The Chukchi Peninsula

The Chukchi Peninsula begins at Chaun Bay, in front of which lies Aion Island. From here the coast runs on fairly straight and consists of a low sandy shore (Fig. 30) rising inland to a hilly tundra. Only in the extreme east is there a larger bay, viz. Kolyuchin Bay, known from the wintering of the *Vega*, with its Chukchi tent village of Pitlekai. The interior of the peninsula is of a decidedly mountainous character. It is crossed lengthwise by a number of parallel ridges, which, beginning with a ridge of primary rocks in the north, belong to progressively younger horizons as one goes south. The northern axis ends on Bering Strait in Cape Serdtse Kamen, 900 meters high. There is a similar ending at Chaun Bay (Cape Shelagski); between the two lie still greater elevations. Cape Dezhnev (East Cape) is a rocky dome 770 meters high (Fig. 31). The highest elevation of the peninsula lies on the Bering Sea side at the head of Holy Cross Bay in Anadyr Gulf; it is the granitic peak Mt. Matachingai, which is 2800 meters high and rises far above its surroundings. Otherwise the elevations remain below 1000 meters, and the relief is not much diversified. The valleys are generally swampy and filled with numerous lakes. Snowdrifts remain the whole year round in protected places, for summer is hardly noticeable before the middle of July and the approach of winter again makes itself felt by the end of August.

Large areas are occupied by tundra, among which the lichen tundra with its gray-white tint predominates; in part, however, meadows of dense grass take its place. Otherwise plant life is here more individualized than farther west; among 220 flowering plants 53 are endemic. The characteristic plants, aside from the cotton grass (*Eriophorum vaginatum*), which also grows elsewhere, are the Chukchi primrose (*Primula tschuktschorum*), *Primula nivalis*, and *Rhododendron kamtschaticum*. The fauna is richer in species than farther west.

The tundras are little inhabited, but the nomads of the interior (Chukchis) own large reindeer herds. Next to reindeer breeding hunting and fishing are of importance. In addition to meat the Chukchis crave a vegetable diet; herein they differ from other Arctic peoples. The coastal inhabitants carry on sealing (by clubbing the animals on land) and fishing. Distinction is therefore made between the coast Chukchis (about 3000) and the reindeer Chukchis (about 10,000). Among the coast Chukchis live a number of Eskimos. This region may become a mining center like Alaska. Gold, for example, has been found in different places.

The New Siberian Islands

Off the East Siberian coast lie a number of island groups, the largest of which is called the New Siberian Islands. Our knowledge

of them we owe mainly to Bunge and von Toll, the latter of whom here met his tragic end without reaching Sannikov Land, conjectured by him to lie to the north. The archipelago consists of four major and a number of minor islands.

The largest and highest is the western island, Kotelny. In its eastern part lie the north-northwest-striking Schmidt Mountains, a peneplained surface of Upper Silurian coralline limestone. The plateau in the middle of the island consists of the same rocks. The details of the relief are due to faulting to such an extent that Toll placed this agency ahead of erosion. The faults belong to two systems, one following the direction already named, and the other a northeasterly direction, thus forming alternating small blocks and troughs with steplike slopes between. The western part of the island is built up of Devonian slates and limestones striking north-northwest, intermingled with diabase in dikes and sheets. A river depression crosses the island toward the northwest and follows step faults in Silurian limestones. In this depression lie late sediments and eruptive rocks covered by Quaternary sediments. Trap rocks make up the highest mountain in the interior, Malakatyn-Tas, 350 meters high, with a tabular surface and step slopes.

The easternmost island, Novaya Sibir (New Siberia), is less than 100 meters in elevation. Its core is formed by the Hedenström Mountains, also striking north-northwest, an old erosion surface consisting of steeply folded Miocene sediments with bituminous coal seams, the so-called Wood Hills, which formerly were taken to be accumulations of driftwood. Aside from these Tertiary hills and an unimportant outcrop of Jurassic rocks the island consists of Quaternary deposits and ice masses. Here, too, a large valley follows in many windings the two characteristic fault lines.

Between these two islands lies Faddeev (Thaddeus) Island. On its coasts only Quaternary formations have been noted, but here, too, certain outlines point to a north-northwest strike and therefore to older rocks.

On Great Lyakhov Island, the fourth major island, lying between Kotelny and the mainland, there are exposures of granites in several places but only in slight elevation. The rest are Quaternary deposits.

The fact that the whole group is dominated by the same two intersecting tectonic directions that prevail on the mainland opposite illustrates the close relationship of the two areas. The sediments and trap rocks which form part of the structure of the islands also establish a relation with the Verkhoyansk arc, which reaches the coast southwest of them. Elevations are slight on all the islands. The mountains are worn down to low stumps partly by Quaternary transgressions, partly by ice.

However, in horizontal extent all the mountain remnants are of

less importance than the surrounding and adjoining lowlands. They consist of frozen silts and sands of Pleistocene age which in many cases rest on compact ice masses up to 22 meters thick. From this relative position Toll concluded that the ice was of fossil character and called it stone ice. However, it also seems possible that it may have been formed recently under the covering layers of soil. It exists almost wholly in river valleys and forms imposing cliffs (Fig. 33) along the valley slopes and on the coast, particularly on Great

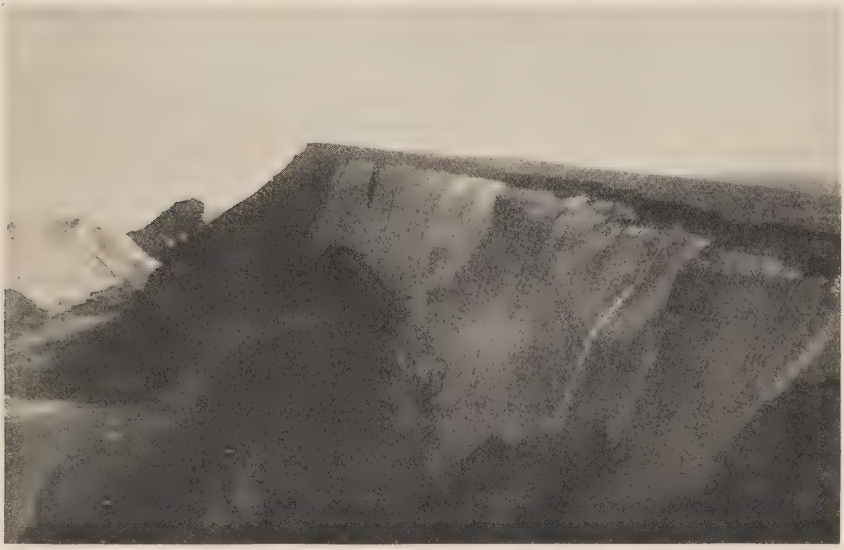


FIG. 33—A cliff of fossil ice on Vasilevski Island, one of the New Siberian group between Kotelny Island and the Lena Delta. (Photograph from N. A. Transehe.)

Lyakhov Island. If the temperatures were raised these cliffs "might change into a liquid porridge and dissolve" (Bunge).

Low Pleistocene sands occupy almost the whole area, called Bunge Land, between Kotelny and Faddeev Islands, merging with the former on the west and becoming still lower toward the east, where they are separated from Faddeev in summer by open water. Their seaward margin is so flat that in summer it shifts back and forth two kilometers with the tides. Nevertheless to show the whole of Bunge Land as a shoal, as some maps and charts do, is misleading. Because Bunge Land is less subject to insolational and erosional attack owing to its flatness its winter snow cover remains longer than on the more undulating adjoining areas.

Among the fossils of the Quaternary deposits the most notable is the mammoth. Not only skeletons and teeth but whole bodies of these great animals with their hairy hides have been dug up from the layers in which frost had preserved them, on the archipelago as well as in the Lena and Kolyma regions and at many other places in

Siberia, even south of the Arctic Circle. The animals have a present economic value because of their tusks. The silty strata also contain the remains of the rhinoceros, horse, deer, antelope, and tiger. The

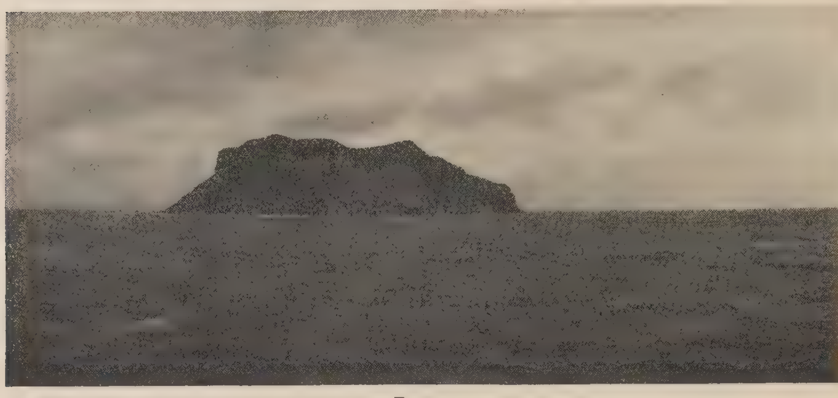


FIG. 34

FIG. 35

FIGS. 34 and 35—Two small islands rising from the continental shelf northeast of the New Siberian Islands: Vilkitski Island (Fig. 34), discovered in 1913 by the Russian Hydrographic Expedition, and Bennett Island (Fig. 35), discovered by De Long in 1881. On the northern shore of Bennett Island, shown in Figure 35, the glaciers descending from the névé on the plateau surface do not extend down to the sea level, whereas they do on the southern shore. (Photographs from N. A. Transehe.)

plant fossils consist of alders (*Alnus fruticosa*) and birches (*Betula alba*) of large size, which point to a warmer climate in a period after the Ice Age. It is only in several degrees of latitude farther south that we now find similar vegetational conditions.

The present vegetation is poor in species and growth. Kotelny has 36 flowering plants. The formation is that of the dry tundra. In extreme cases it becomes stony tundra, which is not much different from stony desert. The color of the soil is gray-brown; only well-watered valleys with their green grass impart variety to the monotonous picture. The July mean is 3.7° C. The temperature in all months is below that at the mouth of the Lena. The islands are visited by collectors of the mammoth remains.

De Long Islands

To the northeast of the New Siberian Islands there lies, still on the continental shelf, a group of smaller islands with which, as with that archipelago, are connected memories of the tragic fate of an expedition, namely that of the *Jeannette*. The largest of the islands is Bennett Island in latitude 76° 40′ N., on which De Long set foot in 1881. This island is a rocky plateau 200 square kilometers in size whose vertical walls of black trap rise 300 meters high in marked contrast to the white snow cover which lies over it and which sends down a number of glaciers (Fig. 35). The basalts, probably of late Tertiary age, cover slates that contain coal and that correspond to the Wood Hills of the New Siberian Islands. The slates in turn rest on a foundation of Cambrian and Lower Silurian strata, as a result of which this distant outpost is brought into structural connection with the East Siberian plateau. The valleys are scantily covered with tundra. Mammoth remains were found here. Flocks of birds breed on the cliff faces.

To the east the small Henrietta Island rises to a height of nearly 1000 meters and lies for the most part under an ice cap. Close by lies Jeannette Island, farther south Zhokhov Island and Vilkitski Island (Fig. 34).

Wrangel Island and Herald Island

Still farther to the east Wrangel Island stands guard over Bering Strait. This island has played a rôle in expeditions that entered the Arctic by way of Bering Strait, the latest of which was that of Stefansson. Russia claims ownership of it, though nationals of British and American origin have set up claims that receive no active or constructive support from their governments. Recently (1924) the Soviet Government sent a man-of-war to hoist its flag over the island and intends to colonize it. In normal years the island can barely be reached. It is only 4700 square kilometers in size and consists of granites and crystalline slates. It is traversed in a west-east direction by three mountain ranges, whose strata are in part vertical, and is in places surrounded by low alluvial land. In general it is mountainous

and hilly and scantily covered with tundra. The highest mountain, Gilder's Head, is 900 meters high. Mammoth tusks have been found on the island.

Near by the smaller Herald Island, which consists of the same terrane, rises steeply to a height of 350 to 400 meters. It is also occupied by a scanty flora and by bird "bazaars."

The Siberian Sea As a Trade Route

The coast of the Arctic Sea has in an apt metaphor been called by Makarov "the façade of Russia's mansion." Indeed to no other side of the giant structure has so monumental a voyage of exploration been made as the Great Northern Expedition (1734–1743), whose surveys have remained fundamental to this day, even if they have been substantially supplemented by the work of Nordenskiöld, Nansen, and Toll, and are only being superseded in places by such work of greater refinement as that carried out by the Russian Hydrographic Expedition of 1910–1915. As early as the eleventh, twelfth, and thirteenth centuries the Russians carried on a brisk trade with the mouth of the Ob and Yenisei. With the newer development of Siberia the façade became more and more prominent economically, and hand in hand with that development went in recent years a renewal under Russian leadership of the endeavors to achieve a northeast passage—in a different sense, however, from that of the days from Willoughby (1553) to Nordenskiöld (1879). Today it is no longer a question of connecting the two world oceans by this route but rather of drawing this Arctic façade into the sphere of influence of world commerce, be it by way of the corner at Bering Strait or by way of the Ural corner or both. For this reason it is no mere chance that Russia has been the first so energetically to develop the ice-breaker as a tool. For Nordenskiöld nearly to have achieved the passage in one year and to have been forced to winter only just short of Bering Strait was due to exceptionally fortunate conditions. Vilkitski, who repeated the voyage in the reverse direction in 1914–1915, was also not able to avoid a wintering. Still greater difficulties were met with in recent years by Amundsen's *Maud*. The main obstacle to normal commerce along the whole front is represented by the massive capstone of Taimyr Peninsula, and the problem today therefore resolves itself into two parts: (1) to link up with the west, by way of the Kara Sea, the hinterland of the West Siberian rivers; (2) to connect Eastern Siberia as far as its great river, the Lena, with the commercial area of the Pacific zone.

The first part of the problem, after the voyages of Nordenskiöld and Wiggins in the seventies, was opened up again by the construction of the Siberian railway, by the Russo-Japanese War, and by the

World War, and was promoted actively during and before the World War especially by the director of an Anglo-Norwegian company trading to Siberia, Jonas Lied. After the war voyages began again immediately by English, Swedish, and Russian vessels. There can no longer be any doubt that the sea route will continue to increase in importance in West Siberian trade, especially for the exportation of cereals, wood, cattle products, etc. Barents Sea, thanks to offshoots of the Gulf Stream, gives hardly any trouble; and the continuation of the voyage either around the southern or northern ends of Novaya Zemlya or through Matochkin Shar is possible according to circumstances. It is only the Kara Sea that offers a formidable obstacle. Much ice forms there and is held together, particularly on its eastern side, as a consequence of the shallowness of the water and the lack of currents; whereas on its western side the ice is brought down from the north. Thus both sides are unfavorable. But the ice situation changes from year to year and from week to week according to the winds and the currents. In favorable summers open water may be counted on for three months. Conditions like this require a patrol service such as has existed since 1913 in the form of a number of wireless stations; these could be supplemented by airplanes, as suggested by Nansen.

Although the East Siberian rivers in their headwaters approach closely to the coasts of the Sea of Okhotsk, they are separated from it by a high mountain wall, so that even here there is no other possibility of opening up the interior than by way of the coast of the Arctic Sea. The newer attempts began only in the last years before the World War, both by American and Russian trading vessels as well as by the Russian ice-breakers engaged in surveying the coast. From the results of these voyages it appears that the Kolyma can be reached as a rule and often the Lena. To be sure, the latter is ice-free at its mouth for only two and a half months; Bering Strait becomes ice-free after the middle of June; Cape Serdtse Kamen only at the beginning of July. A westward current follows the coast, tears off the ice, and drives it off shore, so that in favorable years its limit withdraws in August and September to Wrangel and Herald Islands. Vessels have succeeded in making the return voyage at the end of October and even as late as the first of November, but in general October brings with it the danger of being frozen in.

Bering Sea, Its Islands and Coasts

We can hardly proceed to the other half of the Arctic by way of the 92-kilometer-wide Bering Strait without at least casting a brief glance at Bering Sea. The mainland stumps on both sides are in close structural connection. Bering Sea itself is a vestibule of the

Arctic Sea, its shores and islands in general having polar characteristics, not excepting even the active economic region around Nome. History and economic development show the same unity, and in the winter there is trade from one continent to the other over the ice.

The outlines are literally symmetrical. Northeastern Asia and northwestern America stretch out two end lands toward each other. From the southern portion of each extends a narrow peninsula, Kamchatka on the one hand and the Alaska Peninsula on the other,

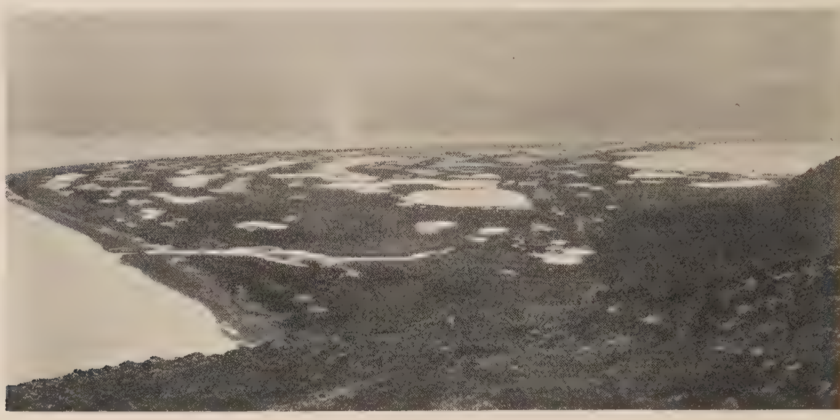


FIG. 36—Cape Prince of Wales, Alaska, seen from Cape Mountain (in the foreground) overlooking the sand-spit-enclosed marsh toward Lopp Lagoon (right background). The houses of the village of Wales may be made out back of the beach on both sides of the small stream debouching to the left. The picture was taken at midnight on June 22, 1926, and shows the sun in its extreme northern position. (Photograph by C. M. Garber.)

and between the two hangs the volcanic island arc of the Aleutians as the southern limit of this marginal sea. Its northern limit is formed by two similar peninsulas which project from the end lands like the wings of a drawbridge: the Chukchi Peninsula and the Seward Peninsula. Between the two lies the narrow rift of Bering Strait.

Both shores of Bering Sea are of transverse structure. The larger bays are Norton Sound and Bristol Bay on the one side and the Gulf of Anadyr and a nameless bay on the other side. The Yukon River has its counterpart in the Anadyr. There are differences in detail. The American coasts and waters are in part flatter and shallower than the Asiatic. The two capes of Bering Strait, Cape Dezhnev (East Cape) and Cape Prince of Wales, are also differentiated in this manner (compare Fig. 31 with Fig. 36).

The outward resemblances are in part caused by the internal similarities. It is the Alaskides that, according to Suess, carry forward Asiatic structure by way of Bering Sea into America until they coalesce with the folded mountains of the Pacific system of the Cordillera. The most continuous of the Alaskides is the Aleutian Islands arc. On the south it is paralleled by a deep-sea trough which attains

a depth of 7400 meters. It consists of a long Mesozoic range with many recent and for the most part still active volcanoes, of which several are 3000 meters high, the whole arc being connected by way of the Alaska Peninsula with the Mesozoic outer belt of the Alaska Range. The Commander Islands, which limit Bering Sea on the southwest, are two strips of land trending northwest and consisting of basalts and Tertiary sediments—Bering Island and Copper Island. As here on the southern margin, so also throughout Bering Sea, Tertiary eruptive rocks occur frequently. The whole of Nunivak Island, the Pribilof Islands, Hall and St. Matthew Islands, and the non-granitic portion of St. Lawrence Island confirm this; likewise several stretches of the coast near the mouth of the Yukon, on Seward Peninsula, and in the Chukchi region. The Aleutian Islands, together with the deep-sea trough on one side of them and the deep marginal sea on the other, clearly constitute an Asiatic border element built into the mountain structure of America. The characteristic intrusive rocks of Seward Peninsula reappear on the Diomede Islands of Bering Strait and, beyond, on Chukchi Peninsula. Indeed, in the distant New Siberian Islands Suess believes he is able to recognize the continuation of the De Long Mountains of Cape Lisburne, Alaska.

According to its bottom relief Bering Sea may be divided into two halves, a southwestern deep basin, in which depths of 4000 meters are attained, and a northeastern shelf sea whose depths average about 100 meters. The latter washes the shores of the two peninsulas that form the immediate connection between the two continents and is continued in the floor of the Arctic Sea off the northern coast of Siberia and Alaska, which is likewise shallow in depth.

The water in Bering Sea has a mean annual temperature of only 4° C. As a result of its inclusion between two land areas with a highly continental climate, much ice is formed every winter. Through the currents and the winds this is transformed into pack ice; its limit in winter runs parallel to the Aleutian Islands by way of the Pribilof Islands to Bristol Bay. At the beginning of summer southerly winds set in and drive it back. The way is then clear for the whalers and for communication with Nome. The Pribilof Islands are as a rule free from ice about the first of May, Bering Strait after the middle of June. The summer remains cool, however; St. Lawrence Island has a July mean of only 6.6°, and the 10° July isotherm bends out like a pouch to include the whole of the Aleutian Islands. These islands are unforested for this reason and because of the wind, as are the Commander Islands and the Alaska Peninsula; they carry only dwarf timber, stunted bushes, meadows, and a luxuriant growth of grass, which is favored by the abundant moisture (Commander Islands, mean annual relative humidity, 90 per cent). The flora characterizes the Aleutian Islands as a transitional region between Japan and the

Pacific side of America on the one hand and the Arctic on the other. From the Pribilof Islands about 200 flowering plants are known. They too, like the Aleutians, belong to the belt of sub-Arctic meadows. Myriads of sea birds fly about them, and seals occupy their shores in immense numbers.

The tribes that live around Bering Sea are the Chukchis, the Koryaks, the Aleuts, and the Eskimos. The Chukchis inhabit the peninsula named after them and also territory farther south. South of them come the Koryaks. The Aleuts begin with the Commander Islands; the population of these islands is more than 600, among whom there is much intermixture with Russians, Eskimos, and Asiatic tribes. The native inhabitants of the islands in the interior of Bering Sea as well as the American mainland side are for the most part Eskimos.

Russia and England first became acquainted with Bering Sea through some of their polar undertakings: Russia in the first half of the eighteenth century mainly through Bering's voyages; England through Cook, who on his last voyage in 1778 passed through Bering Strait, reached Icy Cape (70⅓° N.), and brought back the first maps of and observations on the coasts of Alaska. The Russians soon began hunting and fur trading and after Cook's voyages founded the Shelikov Company, a trading concern which became the Russian-American Company in 1788. Thus Russia at first reigned supreme and reached out beyond the Aleutians to Alaska, attracted by the abundance of animal life in the sea and of fur-bearing animals on the land. By the middle of the nineteenth century the coasts of Alaska were for the most part known to the Russians. Then, however, concurrently with their southward advance along the Asiatic coast they abandoned the polar north and in 1867 sold Alaska to the United States. Of the two Diomede Islands in Bering Strait, one belongs to Russia, the other to the United States.

American activity in Bering Sea has been related mainly to the fur seal industry. As early as the seventies of the last century 100,000 pelts of the fur seal alone were taken annually on the Pribilof Islands. These islands, which are American territory, and the Commander Islands, which are Russian, are the two main rookeries of these animals. Sea otters, whales, and fish are also caught. The sea otter catch on the Commander Islands, where it was once important, has practically disappeared, although Steller was still able to catch 900 head of these valuable animals in 1741–1742. For one hundred and fifty years the great sea cow has been extinct, which lived only here and fed on the forests of algae on the sea bottom. The population of the Aleutian Islands has also diminished as a result of the destruction of the whales and seals. The consequent loss of income is to a certain extent replaced by the fish-canning industry and by grass weaving. Europeans find life on these lonely sunless islands very hard.

Arctic Alaska

ALTHOUGH the Alaska Range and the mountains that form the backbone of the Alaska Peninsula shut off the mild sea winds from the interior, Alaska, for the greater part, is not Arctic in character. The eight-months-long winter is severe, to be sure, like that of the interior of Siberia; connection with civilized coasts proper is difficult; and the name "Arctic City" for one of the larger abandoned gold-mining towns of the interior illustrates the unusual nature of the region. But, in the interior, agriculture—even to the extent of cereal growing—is still possible; and along the central artery of the Yukon, including its tributaries and the gold-mining regions, luxuriant forest is to be met with, which contains, in addition to the birches, alders, and poplars which are generally known as marginal trees, also the more exacting spruces and pines. Only a narrow strip around the larger indentations of Bering Sea as well as a somewhat broader belt along the Arctic Sea lie beyond the forest limit, and the course of the 10° July isotherm does not deviate much from this limit.

The Western Side

The bays of Bering Sea, and indeed the whole western side of Alaska, present, according to Suess, the picture of a submerged virgation, i. e. a sunken system of divergent structural lines. On the projecting ends of these structural elements the tundra has broader scope; at the heads of the bays, little or none; whereas the sea, because of its ice cover, is equally unfavorable in the bays and at the headlands. The coasts are generally adjoined by low land. Back of the shallow Bristol Bay lie a large number of lakes at a low elevation. In the large projection about the mouths of the Kuskokwim and the Yukon either alluvial lands with salt meadows or Tertiary strata accompanied by basalt abut on the sea—the latter occasionally being the cause of considerable elevations, as in Cape Vancouver, 300–400 meters. Norton Sound is likewise surrounded by low land and is bordered in some places by younger coal-bearing sediments and volcanic rock. Similar formations, as well as lagoons, barrier beaches, and flat moors, surround Kotzebue Sound. Harbor conditions are throughout rather unfavorable, partly because of shallow water, partly because of insufficient protection. Ocean vessels, however, can touch at St. Michael, which lies on a protected bay, and here transfer their freight to shallow-draft Yukon steamers. Nome, which lies on the opposite side of Norton Sound, has only an open roadstead (Figs. 37–38).

The most individual and economically the most important region is Seward Peninsula (50,000 square kilometers). In its outline and structure it is dominated by a west to west-southwest strike,

which direction is that of the water parting between Bering Sea and the Arctic Basin. It has no very pronounced longitudinal ridges but rather individual small ranges and hills (Fig. 39). They consist of Paleozoic and older rocks, frequently broken through by granites and by eruptive rocks of varying ages, including young

FIG. 37

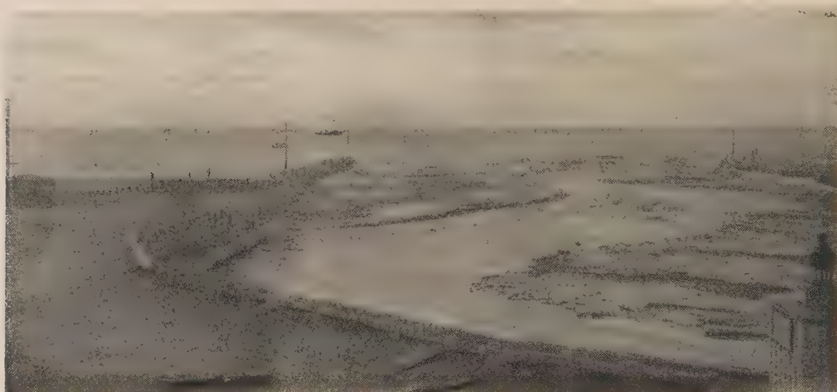


FIG. 38

FIGS. 37 and 38—The harbor of Nome. As the harbor is an open roadstead breakwaters have been built to provide a protected channel, seen at high tide looking landward in Figure 37 and at low tide looking seaward in Figure 38. (Photographs by Alaska Road Commission.)

lavas. Elevations attain 1000 meters only in places, nowhere more than 1500 meters.

In the southwest corner a smaller area is set off from the rest of the peninsula by two narrow bays, Port Clarence and Golofnin Bay, which are continued inland in depressions. This area may be designated the Nome district from the cape and gold-mining town of that name. The gold here is placer gold derived from the quartzite veins of the 600–700-meter-high ridges and washed down into the gulches and down to the beach, being often found abundantly in the gravel. This district is one of the important gold regions of the world and the only one in the Arctic. Although the mean temperature of five mid-year months is above freezing, that of July does not reach 10° C.

FIG. 39

FIG. 40

FIG. 41

FIGS. 39–41—Views on Seward Peninsula. (Photographs by Alaska Road Commission.)

FIG. 39—Looking north-northeast down the valley of the Fox River, a small stream about 15 miles inland from the southern coast in 163¾° W. The rounded tundra-covered hills in the foreground and the isolated range in the distance with its sharper granitic forms (Bendeleben Mountains) are characteristic of Seward Peninsula topography.

FIG. 40—A gold mining camp near Council in the southeastern part of the peninsula. In the foreground gravel that has been washed for gold.

FIG. 41—Modern utilization of an ancient resource: hauling driftwood by tractor from the beach to build a corduroy road.

and August generally brings cold rain and fog with raw winds. However, the coast is as a rule free from drift ice from July to October. The interior with its monotonous tundra has, since the gold rush, become still more barren inasmuch as the tundra has been burned over in order to uncover the gold deposits. In some respects, therefore, Nome, although its position is not so far removed from the civilized world, is in a less favorable area for settlement than the mining towns in the interior forested region of Alaska. The winter climate, with a mean of −17.4° for the coldest month and a mean minimum of −38°, is quite damp and windy as compared with the interior and, in addition, changeable.

The original inhabitants were Eskimos, evidently less than 1000 in number, fisherfolk scattered along the coast. Through them missionaries became aware in 1898 of the gold-bearing sands of the coast. In the spring of 1899 gold seekers streamed in from the Klondike and California, from China, Japan, and Siberia, in fact from all parts of the world. In that year the tent and corrugated-iron city of Nome counted as many as 5000 persons. The next year it grew to 12,000 and then decreased again when the placers were exhausted. Other cities rose in the vicinity. A narrow-gauge railroad leads from Nome into the interior for 130 kilometers; for a time the cars were drawn by dogs, now by a gasoline engine. Steamer connection with the Pacific coast exists from June to the end of October, and the cable to St. Michael by way of Norton Sound is now replaced by wireless. The district yielded gold in 1906 to the value of $7,500,000, in 1910 of only $4,600,000, and in 1921 of only $1,300,000.

The Arctic Sea Side

In contrast to the western transverse coast, the northern coast is neutral. Lacking major articulation, this flat coast (Fig. 42) is divided in detail by headlands, river mouths, deltas, in part by lagoons, barrier beaches, and islands. Where the low shore bluffs break off steeply, embedded blocks of ice are often exposed; these, according to Leffingwell, originate in frost cracks. Back of the Quaternary lowland there follows inland the gently rising peneplain (Figs. 43–45) of Tertiary and Mesozoic rocks, and back of this again, sharply defined, the more than 2500-meter-high folded mountain ranges known collectively as the Brooks Range (formerly Endicott Mountains; see Figs. 46–47). This whole mountain system constitutes a folded arc somewhat concave to the north, which has its northwesternmost extension in the De Long Mountains. In front of this range, at Cape Lisburne, lies a rich coal field of Mesozoic age. Farther to the northeast other coal seams occur along the coast, and the occurrence of petroleum has led to the establishment of a reserve by the United

States Government. The whole range consists mainly of Paleozoic limestones, slates, and sandstone. It was formerly considered a part of the Rocky Mountain system but has latterly been recognized as an independent Arctic mountain system which was folded in the early Tertiary. Though now unglaciated it was occupied by glaciers in the Ice Age.

As the Brooks Range trends almost due east-west and the coast consists of two segments meeting obliquely at Point Barrow, this

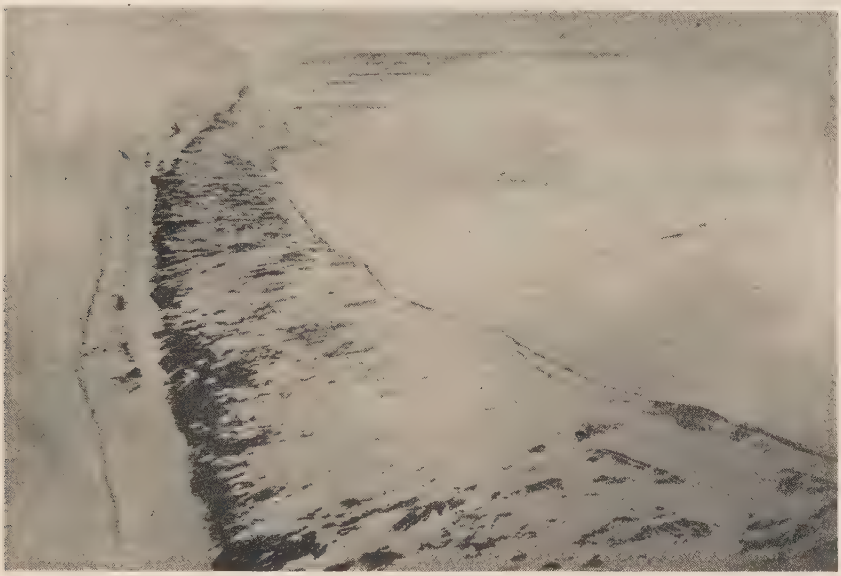


Fig. 42—Lagoon coast of Arctic Alaska west of Point Barrow seen from the air. It was at this point that the *Norge* first reached land after crossing the Arctic Sea. The photograph, taken in May, 1926, from that airship, to a certain extent illustrates the slight differentiation between snow-covered land and ice-covered water even in a transitional season. (Photograph from Lincoln Ellsworth.)

Arctic slope forms a triangle which is only 10 to 20 kilometers wide at Herschel Island and 200 kilometers wide at Point Barrow. In both its belts, the coastal lowland as well as the higher tableland, it is true Arctic tundra. The monotony of the coastal plain is often interrupted by domelike earth hillocks rising 10 or 15 meters or more above the plain, which consist of the same gravelly and peaty material and often have a crater-like depression containing a pond. The explanation of their origin is still obscure. Small grass tussocks also rise from the tundra, and polygonal soil occurs. Lakes and swamps are scattered over the plain and make travel difficult in summer, limiting it to certain customary rivers. Inland on the plateau the rivers are deeply entrenched and have steep walls. The Noatak flows westward in a longitudinal valley to Kotzebue Sound, and in its upper course the Colville is a longitudinal river. The majority of

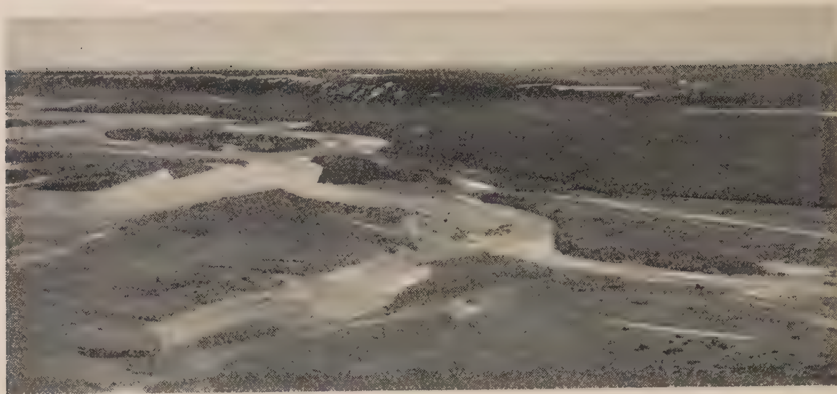


FIG. 43

FIG. 44

FIG. 45

FIGS. 43–45—General aspects of the plateau that lies between the Brooks Range and the Arctic plain of northern Alaska. (Photographs from Philip S. Smith.)

FIG. 43—View south up the Killik River from a point above its junction with the Colville River in about 153° W.

FIG. 44—The Killik River crossing a morainic belt in the plateau region.

FIG. 45—A small tributary of the Ikpikpuk, a river that flows northward into the Arctic Sea in 154° W. The upland in the background (south) is the nearly smooth plateau that forms the divide between this stream and the longitudinal course of the Colville.

the other rivers, including the lower course of the Colville, flow northward parallel to each other into the sea.

Along one of these rivers Arctic willows approach the coast. Dwarfed willows rarely exceed 1½ meters in height but occur so abun-

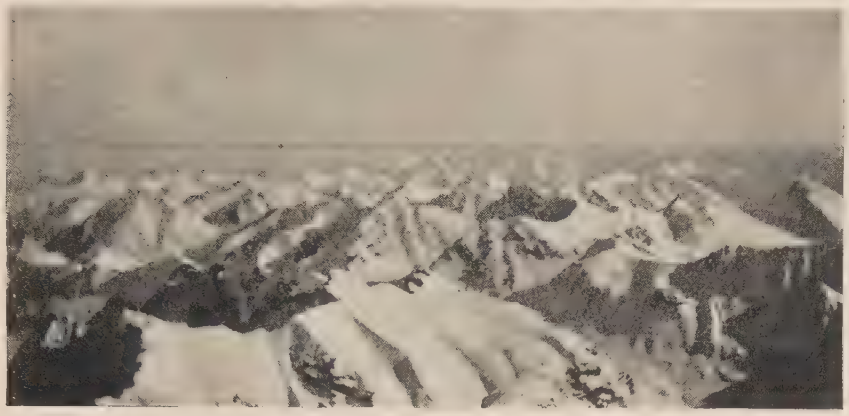


FIG. 46

FIG. 47

FIGS. 46 and 47—The Brooks Range, the mountain system separating the Yukon Valley from the Arctic plain of northern Alaska, seen from the air. In Figure 46 the Arctic plain appears in the background bounded by a faint line representing the shore. Figure 47, looking north, shows the mountains at the head of Wild Creek, a south-flowing headstream of the Koyukuk whose headwaters interlock in 151° W. with the north-flowing Anaktuvuk River. (Photographs by G. H. Wilkins.)

dantly along almost all the rivers that they furnish the Eskimos with fuel and with material for the framework of moss or sod huts. A like purpose is served by driftwood along the coast between Herschel Island and Point Barrow. It once lay in quantities around this point itself; but now it has been used up by the large settlements, especially

FIG. 48

FIG. 49

FIGS. 48 and 49—Eskimos employed by American whalers. (Photographs from Jack Hadley.)
FIG. 48—Eskimo canoes under sails and paddles towing a whale (just left of bow of boat in foreground) to the floe for cutting in. Arctic northern Alaska.
FIG. 49—Cutting for blubber and meat on the floe edge.

since the Eskimos, under the influence of missionaries, are building their houses in the white man's way—houses from which they now try in vain to exclude the cold and dampness by burning fuel, whereas formerly they led a comfortable and healthful life in their well-ventilated snow huts warmed by tallow lamps. West of Point Barrow driftwood is also lacking today—here for the reason that the

Yukon Valley has been largely denuded of forest and the current that comes up from Bering Sea coast has none to carry. East of Point Barrow flows a current coming from the Mackenzie. Both meet at the cape in an acute angle. This causes an offshore tendency, owing to which quite a number of whaling vessels have been driven out between ice floes into the unknown.

The climate is typically Arctic along the coast. Fifty kilometers inland conditions are quite different in summer: whereas the coast

FIG. 50—A whaler's family at Baillie Island, Cape Bathurst. The father is an American of Danish extraction, the mother an Eskimo woman from Cape Prince of Wales. (Photograph from Diamond Jenness.)

is overcast, damp, and cold, the weather in the interior is stable, clear, and warm, even to discomfort. Far inland the temperature may even reach $+30°$ C. In winter in the interior temperatures as low as $-62°$ have been observed; a large annual range therefore obtains here as in Siberia. The coast itself continues warmer in winter but is much stormier. The mean of the coldest month at Herschel Island is $-28.8°$, that of the warmest month $6.9°$. At Point Barrow snow begins to fall again by the middle of August and the coastal ice holds until July.

The Arctic slope was once a single vast pasture for caribou. The

Eskimos hunted it here and even in the forested mountains. Through the advent of civilization it was nearly exterminated. Then in the nineties domesticated reindeer were introduced from Lapland. The fox was also much sought after, especially the blue fox, which occurred more frequently in Alaska than farther east. The most important animal in the fur trade is the Arctic fox. The walrus, too, is found in considerable numbers in this region, especially west of Point Barrow; likewise the bearded seal, whose fur is valued as a covering for boats and for the soles of boots. The polar bear is not frequent. Among birds, the ducks and eiders are abundant and useful.

Arctic man in Alaska has recently undergone radical changes in his conditions of life, the focal point of which is Herschel Island in Canadian territory. This island had been discovered as early as 1826 by Franklin, but not its excellent wind-protected harbor. This was first found by American whalers and made the most important base of their fleet along this dangerous coast, otherwise poor in harbors. The valuable right whale occurred here; often only the baleen was used. The first whaling vessel wintered here in 1889–1890; later sometimes more than a dozen. They disappeared again after 1906 as a result of the depreciation of whalebone. But in the life and customs of the Eskimo the terrible intrusion had taken place. To be sure, trade existed previously along the coast, and certain influences from the west had made themselves felt, such as the use of tobacco; but these influences were not catastrophic, whereas the whale fishery was.

Formerly several hundred Eskimos lived on Herschel Island; now there are but few that are racially pure, and widespread miscegenation exists, even between Eskimos and negroes. In the United States portion of this region Stefansson in 1909 estimated that there were only 1000 Eskimos, that is to say one half or one third of the number that existed in the eighties. In addition, they are leaving the interior for the coast because of the disappearance of the caribou; but on the coast they succumb all the more to European influences. Here not only European weapons, whaleboats, and equipment but in part clothing and food, even down to sugar, tea, and butter, have become necessities of life.

Missions also have been established and changed the old customs based on natural conditions. There are postal connections eastward along the coast as far as Point Barrow.

Today the whale fishery, which once busied a fleet of 300 sailing vessels, has less importance than other sea fisheries. Even in 1910 the total yield of the whale fishery hardly amounted to more than $250,000. Sealing has likewise decreased. The principal resource now is in fox pelts.

The Arctic Margin of the Mainland from the Mackenzie to Hudson Bay

The Mackenzie Delta Region

The only large river in the American sector of the Arctic coming from the far interior of the continent, the Mackenzie, debouches through a delta that has a coastal extension of more than 150 kilometers. On its eastern side it is partly flanked by hills and has steep banks as much as 50 meters high. The delta is not a projecting feature; rather, the coast recedes for a long stretch, and thus the area has a continental climate more related to the climate of the whole Mackenzie basin than is that of the coast about Point Barrow to the west or Cape Bathurst to the east. Thus Herschel Island has a mean July temperature 3.3° C. warmer than Point Barrow. Along the edge of the delta the summer warmth may increase still more, and above the delta it reaches 15°, whereas the January mean drops to −32° (Fort McPherson on the Peel River). The mean annual extremes of this place are 27° and −51°. It is very significant that this type of climate, which begins at the delta and which one might call interior sub-Arctic, extends almost uniformly over the whole Mackenzie basin up to latitude 62°. The ice on the large lakes of the basin attains thicknesses as great as in the Arctic Sea—on Great Slave Lake 2 meters, on Great Bear Lake 2½ to 2¾ meters. It also persists almost as long; on Great Bear Lake it breaks up at the end of May only at level places and even in July does not melt completely because of the heavy night frosts, while in some places the floes remain intact throughout the summer. Nevertheless the summer is oppressive for whites as well as natives because of the heat, the continuous dazzling intensity of light, and the swarms of mosquitoes. The mosquitoes persist from one to three months according to the location.

In the delta region the river opens between the middle and end of May and freezes up about the beginning of November. It is navigable to its mouth. There are no obstacles for boats drawing less than 2 meters. It carries immense amounts of driftwood (Fig. 12), which are deposited along the Arctic Sea shore, mainly west as far as Point Barrow. Besides isolated birches and poplars the delta region bears a bush forest of man height and, in addition, extensive meadows with high grass. Agriculture ceases farther upstream—the cultivation of the potato at latitude 67⅓°, of barley at $64^4/_5$°, and of wheat at $62^1/_5$° (Fort Simpson). However, it is in the basin of this river that agriculture has pushed farthest north, and it may still gain in extent. The Hudson's Bay Company has here also extended its trading posts and maintains freight service from port to port on the rivers and lakes. Exploration also has used the basin of the river as

FIG. 51

FIG. 52

FIG. 51—The northern limit of trees on the eastern side of the Coppermine River. The trees are here thick at their bases but rapidly taper off. (Photograph from R. M. Anderson.)

FIG. 52—Cliffs of dolomitic limestone in the canyon of the Croker River (a short mainland coastal stream in 120° W.) 8 or 10 miles from its mouth. (Photograph from R. M. Anderson.)

a natural point of entry: Mackenzie navigated the river in 1789; in 1826 Franklin traveled here, followed by Simpson and Dease in 1837, by Richardson and Rae during the Franklin search in 1848, and in recent times especially by Stefansson.

The Coastal Belt About Cape Bathurst

For the mainland margin between the delta of the Mackenzie and Coronation Gulf the above title is only an outward summing up

because of the lack of an existing name. An inner justification for setting off this strip is afforded by a glance at the map: up to Coronation Gulf the coast displays simple outlines, at all events not that breaking up into projections and indentations that is so characteristic east of that gulf to Hudson Bay. This difference in articulation is in turn founded on structure; through Coronation Gulf runs the important boundary between the Archean rocks of the Canadian

FIGS. 53 and 54—Coronation Gulf Eskimos. (Photographs from Diamond Jenness.)

Shield and the Paleozoic sediments that rest on it to the west, a boundary which runs from the lower course of the Coppermine River to Great Bear Lake and southeastwards by way of all the great lakes. The Paleozoic belt extends beyond the mouth of the Mackenzie. On it rest small patches of more recent formations, partly Cretaceous, partly Tertiary lignites. West of Cape Bathurst and in juxtaposition to the Mackenzie delta there is a series of long lakes a short distance back of the flat coast—the Eskimo Lakes. East of Cape Bathurst dark columnar basalts and diabases over stratified limestone (Fig. 52) frequently appear at places where the coast breaks off abruptly. Cape Bathurst itself projects in a narrow tip from the middle of this whole coastal region between Liverpool Bay on the west and Franklin Bay on the east. Into the former flows Anderson River, along which the forest approaches close to the coast (see also Fig. 51).

Cape Bathurst and the southern end of Banks Island together

form a gateway nearly 200 kilometers wide to the long strait between the mainland and the Archipelago that farther to the east soon begins to become narrower and winding. The stretch as far as Coronation Gulf is called Dolphin and Union Strait. This strait leads into regions which until very recently had been the least explored since the time of Richardson, whereas up to this point civilization had already approached from the west. The cape itself may be called the easternmost habitat of the civilized Eskimos, and Langton Bay behind the cape is the easternmost outpost at which whalers occasionally winter. The Eskimos themselves are in close contact with one another eastwards up to this point, for example through the manner of building their houses and the shape of their sledges; in the west the sledges are only 2 meters long, at Coronation Gulf 4 to 7 meters long. At the latter place Stefansson met with coastal natives who had never before seen whites.

The Peninsula of the Barren Grounds

The Barren Grounds are the continental root of the Arctic in a physical as well as biological sense. There is no other Arctic land area of such size that belongs with so slight exceptions to the Archean; it is a nuclear area of the Canadian Shield and at the same time the supposed original home of the Eskimo. Shaped almost like an equilateral triangle, with its apex in Melville Peninsula, its sides are formed by the northwestern shore of Hudson Bay, the northern coast of the continent, and the forest limit. The first and the third sides cross the Archean, the second side follows quite closely the boundary between the Archean and the lowest sedimentary zone which follows on the north. On this line, therefore, lie the small and isolated patches of Cambro-Silurian, mainly in Simpson Peninsula and the northeastern corner of Melville Peninsula, whereas Boothia Peninsula in its whole character is related to the surrounding islands and is properly considered separated at its narrow base from the above-mentioned triangle.

The western apex of the Barren Grounds triangle lies in Coronation Gulf. This gulf is comparable to the series of lakes that border the Canadian Shield. Just as one side of each of them lies within the Shield and the other within its Paleozoic margin, so does the long gulf divide two geological horizons: Cape Krusenstern on the mainland and Victoria Island still belong to the Paleozoic belt, while, opposite, Cape Barrow on the mainland and the surrounding islands are made of granite and gneiss. The many islands in the gulf lie in parallel northeast-southwest rows—i. e. exactly in the direction of the boundary between the two zones—and throughout have steep coasts to the south and southeast and gently sloping coasts to the

north and northwest—which corresponds to the stratification. Within the extent of the gulf diabases and basalts also occur. Furthermore, copper is found here, especially abundantly at Bathurst Inlet; the natives use it in addition to their stone material and thus hold a special position as to culture among the Eskimo tribes. Also along Hudson Bay diabases occur. But the dominant rocks throughout

FIG. 55—Barren Grounds topography. Near Fort Churchill, Hudson Bay. (Photograph from F. J. Alcock.)

the whole area are granites and gneisses, along the coast as well as in the interior.

The whole interior of the Canadian Shield, which after its early folding seems no longer to have been covered by the sea, except locally, was once a peneplain worn down to a low elevation above the sea and then elevated and dissected by streams and finally glaciated. Except for the higher Melville Peninsula only occasionally does it exceed 200 meters in the Barren Grounds portion with which we are here concerned. The water parting follows the middle line of the triangle quite regularly from Great Slave Lake to the apex at Melville Peninsula. Parallel to it on the one side a number of rivers flow into Chesterfield Inlet. On the other side the Great Fish River (Back River), which was followed by Back in 1834, flows to the north. With this regularity as to major features, the rock surface, which has been polished and rounded off by the Pleistocene ice sheet, combines an irregular undulating relief in detail (Fig. 55). In its depres-

sions lie large and small lakes of all shapes that are connected by rivers with sinuous and youthful, that is, unorganized, courses. About the lakes and ponds swamps extend. The hills are rocky; loose soil lies only in the valleys, and in it coarser materials predominate. Tundra and bare surfaces are characteristic of this nucleus of former glaciation.

The coasts, which are generally steep, are deeply articulated by fiordlike bays abounding in capes, islands, and reefs. Coronation Gulf is sprinkled with islands. Bathurst Inlet penetrates more deeply and with more articulation. Equally long, but narrow like a river, is Chesterfield Inlet on Hudson Bay. To the northeast the bays, in opposite pairs, progressively form deeper indentations, first the estuary of Back River and Wager Bay, then Committee Bay and Repulse Bay, which nearly pinch off Melville Peninsula. This peninsula has further restrictions and is finally separated from Baffin Island by Fury and Hecla Strait, which is of the same character. Noticeable in connection with this opposition of bay pairs is the fact that copper occurs both on Coronation Gulf and on the Hudson Bay side south of Chesterfield Inlet.

The bays carry the influence of the cold seas into the land and, in connection with the many ice-covered water surfaces of the interior, lower the summer temperature greatly as compared with the Mackenzie basin. From Low's records a June mean of 3° C. results for Cape Fullerton (64° N.); this is indicative of summer cold such as is to be met with in the Eurasian sector only along the inhospitable Kara Sea coast of Novaya Zemlya. The forest limit therefore drops from the mouth of the Coppermine River in a rather straight course down to Port Churchill, i. e. from latitude 67° to 59°.

Man also reflects these conditions. The Eskimo occurs not only on Hudson Bay as far south as Cape Churchill but also in the interior of the Barren Grounds, which with its bays, lakes, and rivers everywhere affords him sufficient sustenance. Distinction is therefore to be made between the coast and the inland Eskimos. The coast Eskimos live along the northern edge of the continent as well as along Hudson Bay. In the former region the seal is the main animal used for food and for its pelt; in the latter the walrus occupies that position. Here, between Cape Fullerton and Repulse Bay, dwell the tribe of the Aivilliks, numbering 150 persons; their name signifies walrus hunters. Through being drawn into the American whale fishery this tribe became much civilized and racially mixed. They go inland only in the autumn for caribou hunting in order to get winter clothing. The interior Eskimos, in distinction from the coastal, base their existence on the caribou and salmon. The caribou migrates in the spring from the mainland to the islands and back in the autumn. On these migrations it is driven into narrow defiles and ponds and killed in masses. On lakes back of Chesterfield Inlet live certain

tribes whom Back had already reported and who were visited by Rasmussen in 1922; so far they had been caribou hunters and salmon fishers, but recently they have begun to migrate towards the sea. According to their cultural possessions Rasmussen sees in them the last survivors of the original Eskimos, whose home Steensby also places in the Barren Grounds. The total number of Eskimos in the Barren Grounds doubtless hardly exceeds 1000.

Hudson Bay and Its Islands

ENCLOSED by Arctic lands and in the latitude of Bering Sea lies Hudson Bay, removed like that sea from the other Arctic waters yet in contrast to that sea entirely surrounded by continental land masses. Because of this, Hudson Bay is a distinctly Arctic inland sea. Although the forest limit crosses it and even runs far north on the western side (in the sketch map, Figure 56, note the northwest-southeast direction of this and other limits), the limit of permanently frozen ground and the mean annual isotherm of 0° C. lie far to the south. Only the fiordlike Fury and Hecla Strait joins Hudson Bay, or rather its northern vestibule, Foxe Basin, with the channels of the Archipelago, and connection to outer waters is alone afforded by the 800-kilometer-long Hudson Strait. This may have been the bed of a great ice stream from the central area of former glaciation. The islands in the strait have striae which would seem to point to this conclusion. The depths near Salisbury Island are over 400 meters. Hudson Bay itself is less than 200 meters deep and very shallow near the shore; it is an epicontinental sea in the heart of the Canadian Shield and covers an area of 1,070,000 square kilometers. In the west the shore is low throughout, on the Labrador side it is steep and high, often 600 meters. The western side is undergoing rapid uplift. Nowhere do glaciers flow into Hudson Bay or Hudson Strait. Silurian and Devonian sediments occur only as isolated marginal patches. However, the islands consist mainly of sedimentary strata or are parts of the Paleozoic enclosure of the Shield. The largest of these is Southampton Island; near it lie the next largest, Coats Island and Mansel Island, as well as the smaller

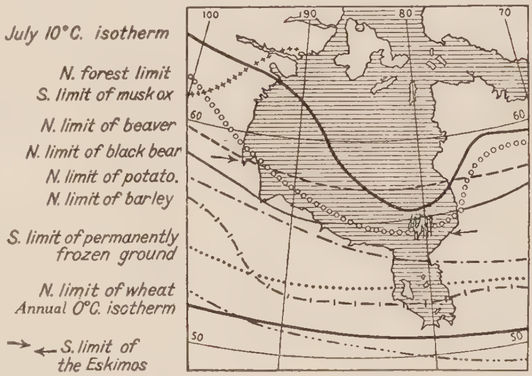


FIG. 56—Limits of characteristic physical phenomena in the Hudson Bay region. Scale, 1:38,000,000.

Nottingham and Salisbury Islands. In the southeastern part of the bay the Belcher Islands group (Fig. 57) covers a large area. The last three are composed of old crystalline rocks, Coats and Mansel Islands of sedimentary rocks, and Southampton Island consists of both elements.

Southampton Island (50,000 square kilometers) is a triangle whose north-south side measures over 300 kilometers. It has a nar-

FIG. 57—The Belcher Islands: looking along the strike of the rocks in the northwestern part of Tukarak Island, the northeastern member of the group. (Photograph from R. J. Flaherty.)

row gneiss and granite zone in the northeast and a larger area of Silurian limestone in the west and south. The former constitutes a low rounded ridge, which, like the Archean islands, Nottingham and Salisbury, strikes southeast-northwest. This ridge rarely exceeds 150 meters in height, is studded with ponds and covered by blocks of rock, and is interrupted both at its northern and southern end by a larger bay. The limestone area rises very gently from the sea and is surrounded by reefs and shoals, which in a few places only allow an approach to within ten kilometers. Inland this area also rises very gently in the form of broad terraces, each of which is only a few feet higher than the next lower. They are covered with limestone débris and because of this are in places so dry that even Arctic vegetation cannot gain a foothold. But on moister ground high grass grows, and around the ponds there are reed grasses. Animal life (caribou, fox, and wolf) is not abundant. The island has only one good harbor in a deeply penetrating bay at the southeastern corner called South Bay.

FIG. 58

FIG. 59

FIG. 58—Port Nelson on the west coast of Hudson Bay in latitude 57° N. (Photograph from F. J. Alcock.)

FIG. 59—Hudson's Bay Company post at Churchill, 200 kilometers farther north than Port Nelson. Churchill has recently been recommended as the terminus of the Hudson Bay Railway, now under construction, instead of Port Nelson. When this railroad is completed, Churchill will become an important outlet port for the shipment of wheat from western Canada to Europe via Hudson Bay. The post shown in the photograph lies on the west side of the estuary of the Churchill River (seen in the background) 4 miles upstream; the proposed port on the east side of the landlocked mouth of the river, with a protected harbor. (Photograph from F. J. Alcock.)

The inhabitants of the island did not come into contact with civilized men until the nineties of the last century. This was the tribe of the Saglernmiut, consisting of 70 persons. Their dwellings, built of limestone, whale bones, and sod, had a shape whose counterpart is found only on the continent as ruins from olden times. At the end of the nineties a whaling firm established a station on the southern coast and deposited there an Eskimo tribe from Hudson Strait, who killed the caribou so quickly with their firearms that the native tribe soon perished and the island became uninhabited. On the other hand Nottingham Island is still inhabited.

The Eskimo tribes in the neighborhood of Hudson Bay and Strait indeed frequently come into contact with whalers and are employed by them. There are whaling stations at several places. The strait between Southampton Island and the mainland was once much frequented; it formerly abounded in seals, walruses, and whales; and of the last more were often caught here in the neighborhood of Whale Point than in all the rest of Hudson Bay.

The whaling interests, together with the possibility of creating here an exit to the open sea particularly for the direct exportation of Canadian wheat, had for some time attracted the attention of the Canadian government to Hudson Bay and Strait and led to the building of the Hudson Bay Railway, still incomplete. Churchill (Fig. 59), is to be the terminus. Churchill lies north of Port Nelson (Fig. 58), i. e. north of the forest limit, and is on the average ice-free for six months. From here cereals, whose cultivation it may prove possible to extend nearly to Hudson Bay, can be carried to the markets of the world; the fur trade and lumber industry, mining, and fishing may also expect improvement. Another advantage is that in this manner production and shipment take place within British territory; Hudson Bay, although three times as large as the Baltic, is a British *mare clausum*. That enhances the value of the route. Furthermore, this route is the shortest route to England from western Canada. Thus Port Nelson, and afterwards possibly the entrance to Hudson Strait, may expect to see a commercial port built; so far there are no larger settlements along the whole extent of Hudson Bay. This Arctic outlet is therefore in a position to improve greatly the trade facilities of the cereal provinces of western Canada.

Hudson Strait is dominated on its southern and northern sides by opposite-flowing currents. The current along the north side comes from Baffin Bay and brings in icebergs, often by the score, even as far as Salisbury Island. However, in the strait as well as in the bay the ice is sufficiently broken up after the middle of July to make navigation possible; and heavier ice does not form again till the middle of November, so that four months are available.

With development of trade as the motive Hudson Bay has again

in recent times attracted exploration to its waters. Its early exploration took place entirely under the spell of the search for the Northwest Passage. Frobisher as early as 1578 had entered the strait. Hudson discovered and sailed the bay in 1610 and was followed by Button and Ingram in 1612, Bylot and Baffin in 1615, and Luke Foxe in 1631. Only in the more recent period of search for a Northwest Passage was the northern termination found by Parry in 1821–1822 to be Fury and Hecla Strait—so named after his vessels. So large a feature as the Belcher Islands was not laid down except as mere dots until 1914 by Flaherty.

The Coast of Labrador

LIKE the opposite wing of a building the peninsula of Labrador on the southeastern side of Hudson Bay faces the peninsula of the Barren Grounds on its northwestern side. As all physical and anthropogeographical limits trend southeastwards in North America (see map, Fig. 56) this peninsula, too, is drawn into the realm of the Arctic—in contrast with the Barren Grounds, however, not in its entirety but only in its coastal belt and, again in keeping with the southeastern tendency of these limits, for a longer stretch on the outer than on the Hudson Bay side. For this reason and also because it is the center of life and trade, it is the Atlantic coastal region that mainly requires characterization here.

The Canadian Shield, to which for the most part the interior of Labrador belongs, is adjoined on the east by an independent marginal mountain system consisting of gneiss and other Archean rocks. It attains its maximum elevation of 2100 meters in its most northerly part, the Torngats (Fig. 60), and then quickly becomes lower before sinking under the sea at its pointed end, Cape Chidley. The lower parts of the mountains have been rounded by the Pleistocene ice sheet, and the higher parts have been carved by local glaciers into peaks and sharp ridges. Throughout the Labrador Peninsula the underlying basement rock is not covered by sedimentary rocks at all and only slightly by glacial or more recent deposits. The interior clearly exhibits the marks of Pleistocene glaciation: the rivers form veritable chains of lakes, many lakes have several outlets, and water plays an important rôle on the slightly undulating low tableland.

Whereas the very numerous rivers flow apart towards the south, west, and north and afford easy communication from coast to coast over their low divides, the Atlantic coast participates in this radial drainage only through the great artery of Hamilton River, which breaks through the coastal range in the huge Hamilton Inlet. The rest of the coastal zone remains independent hydrographically, and back of it and parallel to it run two rivers which respectively drain northward and southward. The further characteristic of this coast is its fiords,

of which the largest and wildest, except for Hamilton Inlet, lie in its northern third. Seaward the coast, especially in its middle section, is beset with skerries. Wall-like accumulations of rock, piled up by the sea ice, often accompany the coast. Strand lines have been cut at

FIG. 60

FIG. 61

FIG. 60—The Torngat Mountains rising from the sea along the northern end of the Labrador coast. Three of the "Four Peaks" which probably attain 2100 meters in elevation are visible in the left background. (Photograph from R. H. Woodworth.)

FIG. 61—The southward-moving procession of icebergs and floe ice off the southern Labrador coast in June. (Photograph from E. M. Kindle.)

different elevations: the highest are differently reported—75 to 100 meters is probable.

In the north, Ungava Bay forms a pouchlike reëntrant, extending southward, and separates the tapering northeastern projection of the peninsula from a massive western stump. In front of the latter lies Charles Island, in front of Ungava Bay the 80-kilometer-long Akpatok Island. This is an area of Silurian limestone and rises to a considerable height from its steep ragged shore. The rest of the coast along Hudson

Strait also rises abruptly, often to heights of hundreds of meters. Except for that island it consists only of Archean rocks, namely granites and gneisses of many forms and colors. Southward along the Hudson Bay coast gneisses preponderate.

All three coasts of Labrador are hemmed in by ice for the greater part of the year. Even on the outer coast large fields of thick sea ice form in winter, and in the spring drift ice from the north floats along shore, especially in the shape of icebergs from Greenland. The summer warmth is thereby lowered to an August mean of 8° to 10° C. in the northern half. The January mean is –22°. The temperatures vary greatly within a short period, as, for example, at the height of summer, according to whether the wind blows from the heated interior or from the ice of the sea. Precipitation amounts to only 500–600 millimeters and occurs mainly in the late summer.

The coast is still blockaded by ice as late as May if there is a landward wind, but the rivers break up at that time, summer fishing begins in the inland waters and bays, and in the north the Eskimos set out on their walrus hunts. But even in June the ice lies heavy in front of the coast (Fig. 61), countless icebergs drift by, and fishing steamers enliven the coastal waters. In July the coast becomes so easily accessible that the mail steamer is able to go as far north as Nain (56½° N.). In August many kinds of berries mature, while out at sea icebergs are drifting by in scores. In September the caribou wander down to the lowlands and southwards, for in October all hills are again covered by snow. In winter begins the trapping of fur animals, which, like caribou hunting, is carried on for months. In March sealing takes the place of caribou hunting.

The temperatures vary even locally within short distances because of the cold Labrador Current; it is this current that exerts its influence on the outer coast, while it is radiation that counts in the fiords. A trip of 30–50 kilometers inland may mean the transition from winter to summer. Thus there is considerably more cultivation inland. The coast lies bare with its somber rocks; about 15 kilometers inland vegetation begins; and far in at the heads of the fiords there may be forests of pine, spruce, and birch (Fig. 62). In the south forests cover the whole interior; but as one goes northward they become sparser and more stunted in growth, leaving correspondingly more space to mosses and lichens, which finally occupy large areas. The forest limit (Fig. 63), bending northward from Hudson Bay, strikes the south of Ungava Bay and then bends back sharply and avoids the coast down to the Strait of Belle Isle. The coastal zone retains a thoroughly Arctic character; the depressions are swampy, the rocky heights are bare, willows and birches are low, and tundra predominates. Only wind-protected sunny slopes of low elevation reached by the melting waters become oases with many small flowering plants. Labrador has a

total of over 400 higher plants. Even in the northeastern projection grass mats and meadows are interspersed in the undulating land.

Bird life is abundant here, but only in summer; of 98 species which Hantzsch collected in the northeast, only 30 bred there and many of these only occasionally. Bird rocks are not characteristic here. Of larger animals the most typical is the caribou, the game animal of coastal and inland dweller both; it ranges from Hudson Strait to Belle Isle. There are also many foxes as well as otters, ermines, wolves, and rodents. Fish occur in great abundance because of the cold Labrador

FIG. 62—Black spruce forest near the eastern end of Lake Melville, which lies just west of the head of Hamilton Inlet on the south-central Labrador coast (about 54° N.). Although the whole Atlantic coast of Labrador is devoid of trees (cf. Fig. 61) because of the chilling effect of the Labrador Current, a luxuriant forest grows back of the coast in the southern part of the Peninsula. (Photograph from E. M. Kindle.)

Current, especially cod and salmon, which are of the greatest importance for the Eskimo, too. In the sea live seals and walruses. Of birds, especially gulls and ptarmigan occur in great numbers. The eider duck, which was once to be found on every island, is now rarely to be seen.

Like the coastal ice and the tundra and the caribou, Eskimos formerly existed in the coastal strip down to the Gulf of St. Lawrence (50° N.) and thus shared with the Indians of the interior the two natural regions of Labrador—regions that even find political expression today, the interior belonging to the Dominion of Canada and the whole outer coastal belt to Newfoundland. In the eighteenth century the Eskimos still extended as far as the southern coast and even made forays into Newfoundland. Now Hamilton Inlet is their boundary, in the same latitude as their southern limit on the Hudson Bay side. To the south of this inlet the sea coast is inhabited by whites. The

coast to the north, although remaining a habitat of the Eskimo, through mission and fishery stations has become a field for white settlement and trade. According to recent findings a people of larger stature and different culture, whose remains are to be found on the outermost islands, once lived here beside the Eskimo; possibly they were Norse immigrants who either died out or moved northwards.

The present-day mission stations were founded by the German Moravians, the first at the end of the eighteenth century: Nain, Okkak, and Hopedale, to which three others were later added. The

FIG. 63—The northern limit of trees in the Labrador Peninsula. Locality: 20 miles west of Fort Chimo, which lies near the head of Ungava Bay (at the eastern edge of the forest limit in Fig. 56). (Photograph from R. J. Flaherty.)

largest is Okkak with 350 inhabitants (Fig. 64). As a result of the existence of these stations, which also carry on trade, as well as the Hudson's Bay Company's posts and the many whalers, the Eskimos have become racially mixed, civilized, and fewer in number. On the outer coast they number slightly over 1000, in all of Labrador a little over 2000. Their most important game on water and on land is being decimated by large-scale hunting; diseases are being introduced; old customs being set aside by civilization and miscegenation; and the race thus led towards its destruction. The kayak, the old symbol of their prowess, has almost disappeared; the umiak, the woman's boat, has been replaced by the motor boat; instead of fur garments cotton is worn; and snow huts are employed only when journeys are made. Since the last century there has also been a whaling and mission station at Port Burwell near the northern cape. Only on the far side of Hudson Strait are there natives who have not yet come into more direct contact with whites.

The bases of life and trade in Labrador are hunting and fishing. The Indians hunt the fur animals and the caribou; the Eskimos hunt the caribou and the seal and catch salmon; the whites hunt fur animals in winter and catch cod in summer. For centuries cod has been the fish *par excellence*, and all parts of it are used. In addition, salmon and seals (formerly herring also) are caught for the organized fishing industry. Since the beginning of the sixteenth century fishing has been carried on here by whites of different nations. Fishing utilizes the

FIG. 64—The Moravian mission settlement of Okkak on the coast of Labrador (latitude 58°). (Photograph from A. P. Coleman.)

summer months and lasts about 100 days in latitude 52°, 75 days in latitude 55°, 65 days in latitude 57°, and only 30 days in latitude 58½°.

Of mineral resources the iron ores are to be mentioned. They are distributed along the coast of Hudson Bay, especially on the Nastapoka Islands, which parallel the coast a few kilometers offshore, in the neighborhood of the forest limit.

Baffin Island

To the north of Labrador Baffin Island extends from 61½° to 74° N.; with its southern and northern cornerstones, Resolution and Bylot Islands respectively, it occupies 545,000 square kilometers. Long in extent and with a much indented coast line, it was first sighted at a number of places and for that reason was first taken to be an archipelago. Its several parts were accordingly given individual names, such as Meta Incognita, Cumberland, Baffin Land, Cockburn Land, Foxe Land, Sussex Land, and others—names still used today for a number of its parts. In its first exploration naturally

the great Northwest Passage seekers Frobisher, Davis, Baffin, and Foxe (1576–1631) participated; a substantial completion of the surveys was brought about by Parry (1819–1823), and for the modern knowledge of the island the voyages of Boas (1883–1884) and Bernier (1906–1910) are fundamental. The island separates Baffin Bay from Hudson Bay and forms the third frame piece about the latter, as it were, by connecting Labrador and the Barren Grounds—Fury and Hecla Strait is only another fiord like those in the Barren Grounds except that it is broken through, and Hudson Strait is a feature like Frobisher and Cumberland Sounds farther north, except that it is somewhat wider and is broken through. Along Davis Strait the gneiss mountains of Labrador appear again on Baffin Island.

FIG. 65—Map of Baffin Island. Scale, 1 : 19,000,000. The correction made by the Putnam expedition of 1927 to the northern coast line of Foxe Land in the southwestern part of the island as shown on existing maps is indicated by a heavy line. This representation should now supersede the current one of the same area.

This high Archean marginal mountain system strikes northwest in three parallel ranges which end in long peninsulas on Davis Strait. It forms the high nucleus of the island. To the west the crystallines of the Canadian Shield and in part Paleozoic sediments adjoin. The latter are limited to a northern and middle stretch of the western side and consist of Silurian limestones. Gneisses and granites occupy the largest areas. This marginal mountain system is accompanied especially in the south by a high, indented fiord coast, in the straits between the small islands of which there are in places very strong and complicated tidal currents. The mountains first rise abruptly 300 meters above the sea and then more gently to the height of the massif. The general elevation south of Cumberland Sound varies between 600 and 900 meters, farther north it increases to 1500 meters and in individual peaks probably to more than 2000 meters. At a

point abreast of Home Bay, however, where the range is constricted, the elevation drops to below 1000 meters, and the same is the case in the extreme north.

The interior is still mostly unknown; the island was first crossed in 1910 by Hantszch, namely from Cumberland Sound to Foxe Basin. On the whole it evidently slopes off from the eastern mountain massif towards the middle and the west. The interior area in the south is occupied by two large relict lakes, of which the larger, Nettilling, lies in northwestward continuation of Cumberland Sound. In part

FIG. 66—The scarp front of the Silurian limestone highland at the southeastern corner of Foxe Basin, western coast of Baffin Island. (Photograph from G. P. Putnam.)

their shores are so flat that in winter lake and plain cannot be differentiated. This plain is the low Silurian limestone plain that reaches the coast of Foxe Basin on the west. At the southeastern corner of Foxe Basin (65½° N. and 74° W.) these limestones end in a scarp front (Fig. 66) about 200 meters high at the foot of which lies a narrow coastal plain of recent origin. Both the limestone coast trending northward from here and the gneiss and granite coast trending westward are so low that the vertical fluctuation of the tides, which in places is as much as 9 meters, shifts the shore line (Figs. 67, 68) about one kilometer on the granite and as much as 8 kilometers and more on the limestone coast. North of Foxe Basin the whole island bends toward the west. Here the interior is a surface of less than 300 meters elevation, among whose rounded heights of Archean rocks lie numerous lakes, as, indeed, is the case in the greater part of Baffin Island. The adjoining northwestern end is a second large area of Silurian limestone, a low plateau with steep cliffs. From the north two deep bays penetrate, Admiralty Inlet and Navy Board Inlet.

The latter, together with Ponds Inlet and Eclipse Sound, cut out Bylot Island from the main island. This is a square-shaped corner pillar with sides 150 kilometers long; it attains elevations of 600 to 900 meters in the interior and consists entirely of crystalline rocks. Oppo-

FIG. 67

FIG. 68

FIGS. 67 and 68—Photographs taken from the same spot at the eastern end of the granitic northern coast of Foxe Land, southwestern Baffin Island. Figure 67 shows high tide; Figure 68, low tide. The range of the tide is nearly 9 meters. (Photographs from G. P. Putnam.)

site it, on the main part of Baffin Island, there is the largest occurrence of Tertiary rocks hereabouts; these constitute an individual terraced region on the south of Eclipse Sound attaining an elevation of 180 meters. A smaller Tertiary area lies in the islands of the eastern coast similar to the occurrence on Disko on the opposite side of Baffin Bay in northern Greenland.

The landforms from south to north show a decrease in the effects of glaciation. Along Hudson Strait the coasts and islands still exhibit the uncovered rounded and polished rock surfaces with undeveloped river valleys, terraced lakes, and striae—all as fresh as if

they were produced by present-day glaciation. However, northward along Baffin Bay the mountains become sharper in outline and the taluses larger, until finally almost all glacial traces are lacking, so that it seems probable that there the local valley glaciation of the present may have been intensified but certainly was not replaced by a large ice sheet; the peaks of Bylot Island rise abruptly above the low, short valley glaciers. These conditions are what would be expected from the peripheral location of the region with reference to the Keewatin center of glaciation and from the northward increase of aridity.

Present-day glaciation is not continuous. North of Cumberland Sound an ice cover seems to lie on the upland; from it glaciers descend into the bays but without giving birth to icebergs of consequence. The lower coastal areas generally become ice-free in summer; likewise the interior, as the ice cover does not extend far into it. South of Cumberland Sound the upland is only partially covered, and south of Frobisher Bay lies the 150-kilometer-long Grinnell ice cap, which sends a small glacier to the sea.

The climate in winter is similar to that in the Barren Grounds opposite. Cumberland Sound with $-32°$ C. has a somewhat colder January than Cape Fullerton. The summer, however, with 6.5° is considerably warmer, and water temperatures between 10° and 15° occur in the lakes. When that is the case it is due to the south winds prevailing in that season. In winter the winds are markedly from the opposite direction, and the climate at that season consequently does not differ from that of the inland Arctic Regions. Cumberland Sound may freeze over almost entirely, but the violent tidal currents keep the ice open at the narrow passages at times when there may be thick and fast ice before and behind them. The size of these water holes changes with the moon because of the tides. In the island and bay maze of the southern coast they are a characteristic phenomenon and increase the winter hunting areas for the natives; but they are lacking north of the sound, where the tides are less strong.

Little vegetation is to be expected in this raw and primarily mountainous land. Barren rocks, black with a cover of lichens, are the rule; they are interrupted rather by the scattered blue lakes and the glistening ice above them than by patches of vegetation. However, in the western plains and in the valleys there are tundra carpets and occasionally on the slopes dwarf bushes and Arctic flowers. Bell collected over 100 higher plants in the south, Borden 31 at Ponds Inlet. Among these were five saxifrages, three species of *Salix*, furthermore *Draba*, *Potentilla*, *Vaccinium uliginosum*, *Cassiope tetragona*.

The two large lakes with their level surroundings provide excellent

grazing for caribou and consequently make capital hunting grounds in the autumn for the inhabitants of Hudson Strait and Frobisher and Cumberland Bays. They also abound in salmon and seals. In the north the abundance of fish in the waters is so great that over a thousand salmon have been caught in a net in one hour. Along the coasts roundabout live seals of different kinds as well as narwhals, white whales, finback whales, and polar bears in abundance; on the land, in addition to caribou, hares, wolves, and foxes. Of Arctic foxes about 3000 were trapped at Ponds Inlet and Cumberland Sound in the winter of 1922–1923. The bird life of the coasts is also abundant, and at the northern end most of the species breed locally. The low, marshy plain at the southeastern corner of Foxe Basin is the breeding place of the blue goose (*Chen caerulescens*).

The natives, who number over 1000, are divided into southern and northern tribes. Between them a long stretch along Baffin Bay from Home Bay to Ponds Inlet is now uninhabited, whereas according to Boas winter settlements formerly existed there. On Cumberland Sound the 400 natives or so are concentrated about the whaling stations and are in their employ. This relationship developed early in the fifties at the stations established by Penny. At the head of the industry are a number of whites; the whaling itself is carried out by the natives. In addition they turn in bears, wolves, foxes, and walruses. Along the southern coast live three tribes, of which the middle one came into contact with the earliest discoverers. In recent times the Scottish whalers have been in the habit of taking this whole tribe on board to use them on the whaling and walrus grounds near Southampton Island. Furthermore, the large lake plain of southern Baffin Island exercises a concentrating influence by drawing the tribes together here from all sides for the summer hunting. The inhabitants of Ponds Inlet have especially large hunting grounds; they often go as far as Foxe Channel but also to Somerset and Devon Islands for musk-ox hunting, and they also include in their territory the less frequented Wellington Channel, west of the latter island, with its walruses and bears. At Ponds Inlet a whaling station was established in 1903. Thus the tribes of Baffin Island, with the exception of those along Foxe Channel, have been brought into uninterrupted contact with civilization, although not to such an extent as in Labrador. Their number is diminished; their cultural possessions and their manner of living are changed; even their settlements and pathways have been shifted; for, instead of the places where driftwood and soapstone are found, the whaling stations have become the foci of attraction. For this reason the Canadian government has recently established an administrative station at Ponds Inlet, as well as at other points in the North, in order, after the example of Denmark in Greenland, to bring system into the economy of the Arctic.

The American Arctic Archipelago (exclusive of Baffin Island)

The Archipelago As a Whole

North of the great land masses of the Barren Grounds and Baffin Island lies the more dismembered area of the American Arctic Archipelago proper. It almost completely occupies the right angle whose one side is formed by northwestern Baffin Island and northwestern Greenland and whose other side is the eastern half of the coast of the continent between the Gulf of Boothia and Cape Bathurst, the western half of this coast facing the open Beaufort Sea. Each side of the right angle is about 1700 kilometers long. The establishment of the outline of the archipelago is primarily the work of Parry and the Franklin seekers, supplemented in the region of Smith Sound especially by Nares. After longer intervals two major achievements of discovery followed north of the Parry group and west of Ellesmere Island—those of Sverdrup (1898–1902) and of Stefansson (1913–1918).

The entrances Lancaster Sound, Jones Sound, and Smith Sound had all been discovered by Baffin and Bylot in 1616, and the main strait, which in its several parts carries the names Lancaster Sound, Barrow Strait, Melville Sound, and McClure Strait, was first navigated by Parry in 1819 as far as Melville Island. By this great east-west furrow the archipelago is divided into two parts. Melville Sound is like a great square on which the streets meet. A wide road runs to the southeast, M'Clintock Channel. This channel and Victoria Strait separate the islands south of the Barrow furrow into a western group consisting of the two large islands, Banks Island and Victoria Island (with a combined area of 260,000 square kilometers), and an eastern group of smaller units—King William Island, Boothia Peninsula, Somerset Island (formerly North Somerset), Prince of Wales Island (together 110,000 square kilometers). North of the Barrow furrow lies an east-west series of islands to which the name Parry Islands had best be limited—Devon (formerly North Devon), Cornwallis, Bathurst, Byam Martin, Melville, Eglinton, Prince Patrick, Brock, Borden (together 155,000 square kilometers). Beyond Jones Sound, Devon is continued by a land of the same character, Ellesmere Island (200,000 square kilometers). In the angle between this island and the Parry Islands there lies a group which may be collectively designated the Sverdrup Islands: Axel Heiberg, Meighen, Cornwall (formerly North Cornwall), Amund Ringnes, Ellef Ringnes, King Christian, Lougheed (together 65,000 square kilometers).

Suess's outline of the structure of the Arctic Archipelago and its relation to the geological foundations of North America, as he developed it nearly forty years ago on the basis of the investigations of the Franklin searchers, has been confirmed and deepened by the

newer explorations, especially those of the Sverdrup expedition and the Canadian geologist Low. The crystalline mountain ranges of eastern Labrador and eastern Baffin Island continue in the eastern half of Devon Island and the southeastern corner of Ellesmere Island. The northern edge of the continent is occupied by the Archean rocks of the Canadian Shield, and on the islands there follows first its Paleozoic margin. Of this formation the limestones of the older

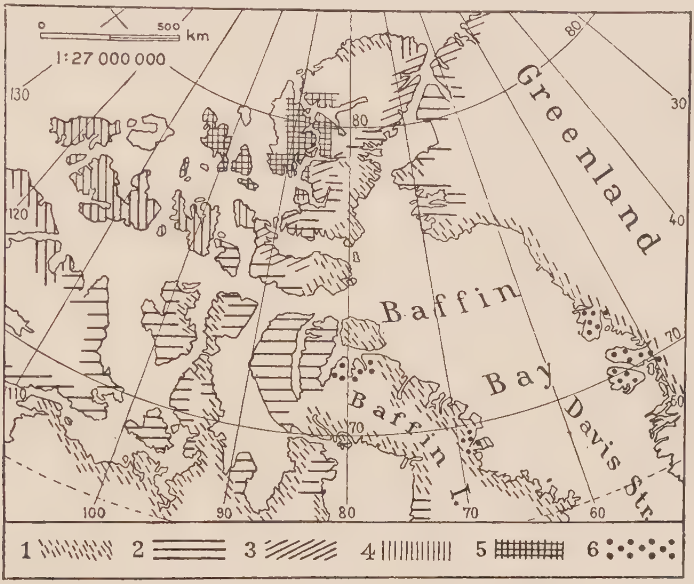


FIG. 69—Geological sketch map of the American Arctic Archipelago. 1, Archean; 2, Cambro-Silurian; 3, Devonian; 4, Carboniferous; 5, Triassic; 6, Tertiary.

Paleozoic extend in general to the Barrow line, falling somewhat short of it in the west and extending beyond it in the east on Devon and Cornwallis, whereas the rest of the Parry Islands is built up of Carboniferous rocks and the Sverdrup Islands, as well as the west and north of Ellesmere Island, largely of Mesozoic deposits. Thus the broad outlines of the geological development are very simple. After an extensive transgression the Cambro-Silurian sea receded to the north. Before the end of Devonian time the Barrow line had already in the main been reached, whereas to the north of it the Carboniferous sea in particular now deposited its sediments without a gap. The extreme northern marginal belt of the Parry Islands was still washed by the Triassic sea, which furthermore covered the whole Sverdrup archipelago and the northern part of Ellesmere Island. At the end of the Mesozoic era, folding and faulting here set in together with eruptive activity. Eureka Sound especially is a deep north-south fault trough which cleaves central Ellesmere Island from the Sverdrup Islands. Shallow transgressions of the Miocene sea affected only a

few marginal areas. At the end of the Tertiary began an uplift which continued into the Glacial Period. At the climax of the latter there followed a general sinking, which, by filling the valleys and troughs, created the sounds and then gave way to a newer uplift which still continues, as attested by strand lines up to 180 meters above sea level. Older maps portray the archipelago as having been covered by a continuous ice sheet in the Pleistocene. Newer researches have shown that that cannot have been the case, for over large areas all evidences of intensive glaciation are absent and, to the south, in Baffin Island, these evidences decrease as one goes northward, as we have seen (pp. 215–216).

The coastal development, in its manifold variety of long straits and bays which often branch like fiords, indicates that the erosional forms of this plateau-like land were drowned and then widened by the sea and, by the cutting down of their divides, changed into a connected network of channels. In the Barrow furrow their depth is generally less than 200 meters; 1000 meters are nowhere attained. These channels exercised a strong influence on the seekers after the Northwest Passage; some of them, like Lancaster Sound, Wellington Channel, and Melville Sound, have had an absolutely magnetic power and in some years have attracted whole fleets of discoverers. On the other hand it is significant that the least accessible and most hidden corner of the whole system, between King William Island and the continent, has received hardly any attention until recent times; and yet it is precisely this channel that alone made possible the Northwest Passage, for it was here that Amundsen managed to find a tortuous way for his little *Gjöa*. A characteristic feature, finally, and one that is based on the configuration of the region, is the joint operation of land and sea expeditions in the period of exploration beginning in 1818 as well as the introduction and perfection of sledge travel in this whole area, where the mobility of ships was soon circumscribed by ice and long journeys were therefore indispensable in order to reveal the complicated outlines. By far the greater part of these outlines were determined on sledge journeys. Lieutenant Schwatka of the United States Army alone covered no less than 5200 kilometers on sleds in 1878–1879 while adopting the mode of life of the Eskimo.

The coasts of the crystalline area are generally deeply indented, the straits in front of them have an accidented relief, and the land rises steeply but generally to relatively low altitudes. The limestone islands rise abruptly in steep cliffs to an elevation of several hundred meters and form extensive tablelands. These sedimentary plateaus carry thinner ice covers than the Archean surfaces. Otto Nordenskjöld has set this relation up as a general law of the Arctic. However, in this case a climatic reason, namely the distance from Baffin Bay,

may be more determining. The islands consisting of Mesozoic sediments, on the other hand, have lower coasts and no great elevations in the interior. The surface is more accidented on Axel Heiberg Island, where the strata have been affected by volcanic intrusions. This is the transition to Ellesmere Island, which has been subjected still more to tectonic and also volcanic processes; but even here the plateau character is as a whole preserved.

Coal seams are exposed in a number of places along the coasts and in valleys, for example at Mercy Bay on Banks Island, on the southern part of Melville Island, on Byam Martin, and on southern Bathurst Island. They have been utilized by a number of expeditions while wintering and would furnish good coking coal.

The position of the archipelago between Greenland, Baffin Island, and the mainland is continental and brings about cold winters, which find their counterpart only in the higher latitude of northern Greenland. Port Kennedy on Somerset Island has a February mean of −38.5° C. But a continental summer warmth is prevented by the ice-filled channels; Port Kennedy has a July mean of +4.5°. At Mercy Bay positive mean temperatures in addition to July (+2.6°) occur only in August; the same holds true in Gjöa Harbor in southeastern King William Island; elsewhere there are generally three months. Whaling in the sounds can count on a season of only six to eight weeks. The temperature variation in winter is not very great in the archipelago because of the ice covering of the straits. It is only along the Smith Sound line that the influence of the sea displays itself in the more unstable weather. Here in winter warm southerly winds can bring about changes of temperature of 20° in a few hours; on such occasions even rainstorms take place.

The winds over the archipelago generally blow from the north and northwest under the influence of the barometric low of Davis Strait. They bring little precipitation, certainly less than 200 millimeters—in many places probably only 100 millimeters. In spring and autumn it falls in the form of misty rain, snow, and fog and especially in spring increases the discomforts of travel caused by melt-water and slush. The small amount of precipitation hinders glaciation; ice covers where they exist are due to the fact that there is open water near by, like the North Water near southern Ellesmere Island, and that southerly winds are more frequent. More than three-quarters of the archipelago is almost entirely free from snow all year; where it falls, the wind soon heaps it up in protected places.

The prevailing northerly winds impart to the water of the whole strait system a motion towards Baffin Bay. It was due to this that the *Resolute*, abandoned in 1854, drifted from Barrow Strait into Davis Strait. In narrow places, as at North Kent Island between

southwestern Ellesmere Island and northwestern Devon, the current becomes intense and keeps the water permanently open.

The vegetation of the area is on the whole determined by the climate, especially by the cold and violent winds which absorb the scant moisture and transform wide areas into deserts. However, it is the ground and not the climate that has a differentiating effect: on the one hand through its form, as a result of which small damp and protected places become oases; on the other hand through the character of the soil, as illustrated by the fact that the Silurian limestones especially, which erode into large blocks, make the poorest soil, while the Archean terrane in the eastern part of the archipelago carries the vegetation that is densest and most abundant in species. Generally even the barren lichen tundra forms no continuous carpet. In addition to mosses and lichens, grasses and reed grasses predominate and, between them, Ericaceae. However, *Salix arctica* occurs up to the highest latitudes. In the watered and insolated oases there develops the Arctic flowery glory of the poppy, saxifrage, *Ranunculus*, spoonwort, and others. Swamps and brooks are covered with algae, which afford food for the geese and other animals. About 200 higher plant species are known from the archipelago, including Baffin Island; but this list probably does not include all existing species. The larger the individual island and the more southerly its location, the greater the number of its species: King William Island, 65; Ellesmere Island, 113; Axel Heiberg Island, 34. For dissemination from island to island the ice of the sea is of the greatest importance; over its smooth surface the seeds are blown by the wind. Hence even a narrow channel is more difficult to cross in case it has no ice cover as a result of the violent currents; this is illustrated by the poverty of the flora of a number of small islands near Devon Island.

Animal life is relatively poor in species but rich in individuals. Ratzel is correct in emphasizing the disparity between the vegetation and animal life, which he says is nowhere more sharply emphasized than in the polar pastures of the musk ox. This animal occurs in herds of as many as thirty in the midst of low and dwarfed vegetation whose distribution is furthermore restricted by the ice, and yet he attains a bodily length of 1.5 meters and a shoulder height of 1.1 meters. There are also four species of land mammals here that are lacking in Greenland. Both circumstances evidently are due to connection with the mainland—indeed the whole Canadian character of the fauna is due to the same reason. The musk ox (see Fig. 17, p. 66), archaic in appearance, ranges from the mainland to Greenland and is really the characteristic animal of the archipelago. The characteristic animals of the Barren Grounds are the lemming and the Arctic hare; whereas the animals of prey, wolf, Arctic fox, ermine, and polar bear, are circumpolar. The caribou migrates from the con-

tinent in summer; Peary found a hibernating species in Grinnell Land. It lives on lichens, the musk ox on grass. Life increases westwards from the barren Silurian limestone areas of Devon Island and attains its maximum on Melville Island, where herds of musk ox numbering as many as 150 have been met with. Similarly animal life becomes more abundant northwards from Devon Island and develops to such an extent at Lady Franklin Bay that Peary was able to base on it the sustenance of his large number of Eskimos. About Eureka Sound also there is teeming life.

Bird life (skua gulls, divers, snipe, and others) likewise generally extends to the limits of the islands. Most of the birds are sea birds, but some land birds occur also, such as the snow bunting and the ptarmigan. The sea birds form colonies, especially about the North Water. Mosquitoes are rarer on the archipelago; on Lougheed Island Stefansson found none.

Only the southern margin of the archipelago is inhabited by men today, but traces of former settlement extend beyond the Barrow furrow and especially far north in Ellesmere Island. Farther to the west Isachsen found no traces on the Ringnes Islands, and Stefansson none farther than on Melville Island. This withdrawal hardly requires a change of climate as explanation but only unfavorable ice conditions for many years as a result of which seal and bear hunting was made more difficult. These animals are more important to human life here than the caribou and the musk ox.

Over the whole archipelago Canada has recently formally extended its political sovereignty. Even on uninhabited Ellesmere Island it established two Royal Canadian Mounted Police stations—one at Craig Harbor on the southeastern corner and the other at Buchanan Bay in the middle of the east coast. The animal life and possibly even the mineral resources open up prospects of profitable exploitation.

Banks Island and Victoria Island

Banks Island is the western wall at which the archipelago south of the Barrow line ends in a nearly north-south trending coast. Its major axis in this direction measures 400 kilometers. The southern third of the island consists of Silurian limestone, which is overlain to the north by Devonian and Lower Carboniferous strata and lastly by Tertiary. Thus the northern part, about two-thirds of the island, is geologically related to the Parry group. The coast abounds in small bays—drowned river mouths. The island has the form of a plateau with culminating elevations generally over 300 meters in height and in the south up to 900 meters; between them lakes are scattered in considerable number. The soil supports a relatively abundant herbaceous vegetation providing food for caribou and

Arctic hares. Musk oxen were still numerous in McClure's time but were exterminated soon after, as the Eskimos crossed the island every summer to plunder McClure's vessel the *Investigator* in Mercy Bay for iron.

"Here was a beautiful country of valleys everywhere gold and white with flowers or green with grass or mingled greens and brown with grass and lichens, except some of the hill tops which were rocky and barren. These hills differed in coloring, especially as seen from a distance, not so much because of the colors of the rock as because different vegetation prevails in different kinds of soil and different lichens on different rocks. There were sparkling brooks that united into rivers of crystal clearness, flowing over gravel bottoms" (Stefansson). The heath plant *Cassiope tetragona* grows almost everywhere in abundance on the island and may be used as fuel; there are also many caribou for food.

Victoria Island is separated from Banks Island only by the narrow Prince of Wales Strait and is organically a continuation of that island. In the extreme northwest therefore the rocks are Carboniferous sandstones; on the rest of the island, Silurian limestones in wide extent. Regional names of parts of the island are Victoria Land, Wollaston Land, Prince Albert Land, and King Haakon VII Land; modern official Canadian usage has eliminated Victoria as a sectional name because of its extension to the whole island and has changed "Land" into "Peninsula" in the case of Wollaston and Prince Albert. Amundsen's officer Hansen was the first to survey the long stretch of coast of King Haakon VII Land along M'Clintock Channel; a piece of this coast still remains unsurveyed. The major axis of the island measures 700 kilometers in a northwestern direction. Of the interior nothing is yet known. Elevations inland are probably below 150 meters. The isolated Mt. Pelly with a height of 250 meters becomes a very prominent landmark along these low coasts. In the southeastern part of the island, what with the dovetailing ice-covered bays, snow-covered low promontories and islands, inland lakes, and skerries, it is hardly possible to make out where the coast line runs. The island fully exhibits that barrenness and poverty of life characteristic of most of the islands farther east because of the sterility of the Silurian limestone.

On Victoria Island Stefansson discovered the "blond Eskimos," 100 to 150 individuals with brown beards, gray-green eyes, and a cephalic index which, it seems, is closer to that of Eskimo half-breeds than to that of pure Eskimos. Reports about such a type had already reached the outside world, through Franklin as well as through Dease and Simpson. Newer investigations, however, cast much doubt on the interpretation of these Eskimos as being of Scandinavian or of half-breed type.

The Boothia Group

The land areas between Victoria Island and Baffin Island and south of the Barrow line may be grouped together as a unit; besides the Boothia Peninsula the group includes the surrounding islands King William, Prince of Wales, and Somerset. Boothia is almost an island; it is connected with the mainland only by the narrow Boothia Isthmus, which is crossed by a chain of lakes. From Boothia Peninsula Somerset is separated by the very narrow Bellot Strait in latitude 72°. The former is almost the inverted image of the latter. They resemble two pyramids, one resting on the apex of the other; each is about 240 kilometers long. Even Prince of Wales Island, which is separated from them by Franklin Strait and Peel Sound, has the form of two upright pyramids: a larger southern pyramid, similar to Somerset, on the base of which rests a smaller. Thus two large bays are formed, Ommanney Bay and Browne Bay. At the southern end of the group lies the small quadrangular King William Island, separated by Sir James Ross Strait and Rae Strait from the mainland. It is in this out-of-the-way corner that the members of the Franklin Expedition met their fate, and here their remains were found by M'Clintock. M'Clintock immediately realized that, in addition to the passage discovered by McClure, another existed directly along the mainland coast. Amundsen, who subsequently achieved the Northwest Passage by this route, wintered at this point.

From the Barren Grounds a strip of Archean terrane strikes north-northwest right through Boothia Peninsula. Its continuation lies directly in the axis of Peel Sound and thus occupies the western coastal margin of Somerset Island and the eastern margin of Prince of Wales Island, and Peel Sound itself is filled with large and small islands composed of rocks of this age. On Somerset Island the coast, made up of crystalline rock, does not rise above 300 meters; in the south it is considerably lower. On both sides of this strip extend the Silurian limestones. They rise along the coasts as steep walls—on the eastern side of Somerset Island to about 300 meters. The horizontal lines of stratification and the vertical lines of numerous erosional gorges give these walls an aspect of gigantic edifices with bastions and turrets. The tablelands of the interior seemingly do not rise much above the elevation of the coastal cliffs—on Prince of Wales Island not over 150 meters. There has been little glaciation of the island; erratics, however, occur.

Over wide areas the islands are bare and barren. Gjöa Harbor on King William Island is surrounded by moss-covered plains with interspersed lakes. Here, at the time of Amundsen's sojourn, 1903–1905, relatively active life developed during the summers. There were flowers and insects and birds, and caribou that came over for summer pasture from the mainland were often present in herds of

hundreds. The inhabitants (Nechilli and others) in this inaccessible corner have not yet come into direct contact with civilization, although through barter with southern tribes they have come to possess iron knives, for example. Driftwood, too, they have to secure through barter. Their fishing implements and bows and arrows are made of caribou bone. Their kayaks, on which they are less dependent than other Eskimo tribes, are described as ugly and awkward in shape.

The Parry Islands

North of the great west-east strait constituting the Barrow furrow a series of islands extends in the latitude of Devon Island and Jones Sound which, excluding Devon Island, we designate as the Parry Islands proper: Cornwallis, Bathurst, Byam Martin, Melville, Eglinton, Prince Patrick, Brock, and Borden. Only Cornwallis, which lies closest to the Silurian corner of Devon, consists of this rock for the greater part; the rest of the belt is occupied by Carboniferous formations and as a result of this circumstance is uniform in character. Between the Silurian limestone and the Carboniferous sandstone Devonian strata are exposed in the coastal cliffs. The contacts strike northeast to east-northeast. The Carboniferous consists of a series of thick white and yellow sandstones with coal pockets; northwards it is overlain by a blue limestone with numerous marine fossils. The coal was first found by Parry on Melville Island and was used on his vessel. In the western part of the belt later strata reappear, corresponding to the circumstance that, south of the Barrow line also, the youngest formations occur in the west, as we have seen. These consist of Tertiary beds with fossil wood (*Pinus*, *Betula*).

Only the westernmost of these islands has a compact central body, to which members are attached, whereas the others consist of members only, as it were—large peninsulas which in turn are split up by bays of all sizes and shapes. Steep shores of 100-to-200 meter elevation—in parts below 100 meters—form the border of the strongly dissected plateaus of the interior, which in general are below 300 meters in height. Melville Island, with its area of 42,000 square kilometers, the largest of the group, has about 60 species of flowering plants, among them *Pleuropogon sabinii*. According to Stefansson it must once have supported more musk oxen than now; perhaps the herds were reduced in numbers by the Eskimos. Additional animals which live here are caribou, wolves, foxes, hares, lemmings, polar bears, seals, but few whales.

The Sverdrup Islands

The angle between the Parry group and Ellesmere Island is occupied by seven larger and a number of smaller islands. Their belonging

to the Triassic sharply differentiates them from the Parry Islands and relates them to the western side of Ellesmere Island. The strata, which consist of sandstones, slates, and limestones, originally formed a slightly tilted plateau dipping northwestwards. In Mesozoic or early Tertiary times this plateau was faulted and divided into smaller blocks, of which some sank and were covered by the sea while others were uplifted. These disturbances were strongest in the marginal zone of the Sverdrup Islands known as Eureka Sound. Here the strata in the form of small blocks often dip 50° to 60°, and in the depressions of the Mesozoic sandstone patches of Tertiary quartzitic sandstone with seams of soft coal are interspersed. Along this line there are also numerous igneous intrusions in the form of diabases and porphyrites, as well as extrusive lavas—all pre-Miocene. On a number of islands coal has been found and utilized.

Axel Heiberg Island, the largest, parallels the zone of disturbance in the form of a long-stretched-out mass. In the south and in the north it is roughly 500 meters high; in the middle occur lowlands consisting of low rounded gravel ridges and along the coast of sand banks of great thickness. These numerous elevations, with the broad, flat valleys between, give the impression, according to Sverdrup, of the land having risen from the sea as an archipelago. The islands in the west also are almost entirely true lowlands in character or low, undulating hilly lands, and their flat coasts make it difficult in places to distinguish between land and water. Glaciation is almost entirely lacking. The vegetation of these low gravel-covered areas is similar to that of the Silurian and Carboniferous zone, although in places the grass cover is somewhat greater in extent. Grasses, mosses, and lichens everywhere are the characteristic feature. From Axel Heiberg Island 34 species of flowering plants, 15 mosses, and a number of lichens are known. Herds of musk oxen have been seen, and caribou pasture on almost all the islands.

Devon Island

Devon Island (formerly North Devon) has in every respect the attributes of a connecting link. On the one hand it is related to the Carboniferous Parry Islands (and lies in the same latitudinal belt), with whose geological formations it forms a direct continuation with its sequence from west to east of Carboniferous, Devonian, Silurian, and Archean. On the other hand it forms a transition between Baffin Island and Ellesmere Island in that, like them, it has Archean on its eastern flank and sedimentary formations in its western part. With regard to the sedimentaries there is a progressive cumulation northwards, only Silurian limestones being represented on Baffin Island, while, on Devon Island, Devonian and Carboniferous appear and

in addition, on Ellesmere Island, Triassic. Devon Island is a rectangle 350 kilometers long lying along the 75th parallel, flanked in the south by the great west-east channel of Lancaster Sound, in the north by Jones Sound, which leads to the Sverdrup archipelago. In the west it is bordered by Wellington Channel, which played an important rôle in the Franklin search expeditions. Across the northern end of the channel a peninsula of Devon Island projects. This projection is divided by the deep reëntrant of Arthur Fiord into two parts, the outer one of the two being designated Grinnell Peninsula.

The Archean eastern part of the island rises to an elevation of nearly 1000 meters and carries a thick ice cover, which discharges through glaciers mainly into Croker Bay. The adjoining sedimentary plateau is lower and decreases westwards to 300 meters, the ice cover at the same time becoming more restricted in that direction and finally disappearing. The granitic surface of the eastern part is, where it is ice-free, an undulating surface, whereas in the limestones of the west the plateau character predominates. Here the coasts rise abruptly to 300 meters elevation, and back of these the interior rises in steps up to 600 meters. Into these limestone walls deep valleys and long bays have been eroded, ending in the west at Beechey Island, the gatepost of Wellington Channel, where Franklin spent a winter and which served as a sort of headquarters during the Franklin search.

The herds of musk oxen and reindeer that pasture on the ice-free surfaces of the western part are sometimes hunted by the Eskimos of Baffin Island, and in Wellington Channel walruses and polar bears are frequent. It is evident that here lies a stretch of the hunting and migrating route that led northwards along Eureka Sound and through Ellesmere Island to Greenland.

Ellesmere Island

The largest island of Arctic America next to Baffin Island extends from latitude 76° to 83° N. (Cape Columbia, 83° 7′). The island thus measures 775 kilometers along its nearly north-south longitudinal axis, while transversely it alternately widens and narrows from an extreme width of 500 kilometers to one of less than 70 kilometers. Indentations occurring in pairs on opposite sides are a characteristic of the island and were for a long time considered to be through-going straits. As a result of these pairs of indentations the island can be divided into four natural sections whose size increases from south to north. Each of these sections needs a name, likewise the whole island as a unit. Heretofore confusion has reigned in the matter of names. In the discovery of the long eastern front a number of Smith Sound explorers participated—John Ross as early as 1818, Inglefield and

Kane in the fifties, Nares and Hall in the seventies, Greely in 1881–1884, and finally Peary after the nineties, whereas the exploration of almost the whole western side is the work of Sverdrup (1898–1902). Thus a number of names were introduced which partly applied to these natural sections and partly extended beyond them, but not one of which is used exclusively for a definite section and for the same extent by all authors. We select the name of Ellesmere Island for the whole, in keeping with present official Canadian usage; and for the four sections from south to north Lincoln Land, King Oscar Land, Grinnell Land, and Grant Land.

In the whole southeastern part of the island the Archean granites of the Canadian oldland are exposed from Harbor Fiord in the middle of the southern coast to Buchanan Bay nearly in the middle of the eastern side. On this northwestwards are deposited the sediments, first those of the Cambrian sea in the form of thick quartzitic sandstones, then the limestone beds of the Silurian sea having a thickness of several hundred meters, then Devonian and Carboniferous sandstones and limestones, and, finally, in a broad connection with the Sverdrup archipelago, the sandstones and limestones of the Triassic sea, after which the Archean again appears along the northern coast of Grant Land. Only here and there in valleys and depressions within the area of the Mesozoic sediments are Miocene strata containing soft coal to be found, and strand lines give evidence of the latest advance and recession of the sea. The Devonian strata which strike the eastern side north of Kane Basin are folded; they thus establish a close connection with northern Greenland. On the other side there is relationship with the plateaus of Axel Heiberg Island beyond the fault and igneous zone of Eureka Sound; dikes and knobs which project above the sandstones and the limestones testify to great igneous intrusions here. Thus it is that the relief is most pronounced about this furrow; parts of blocks, high and low, of different dip and in part of truly mountainous variety of form, are cut out by narrow and often straight bays and valleys. Great fiord bays are characteristic here as they are in the western half of the southern coast and the northern half of the eastern coast. Only in the whole western fault zone the predominant directions are north-south and east-west, whereas in the northeast the northeast strike of the folds evidently is the determinant. The southernmost great fiord systems of the eastern side again follow the east-west direction of penetration; on each side of Bache Peninsula there is a four-fold branching fiord complex, Buchanan Bay and Princess Marie Bay. South of this area, i. e. in the Archean, as well as along the Archean coast of Grant Land, deeper indentations are entirely lacking.

The land in general rises above 700 meters. Elevations of over 1200 meters are attained in the United States Range, which crosses

Grant Land in the fold direction. South of it and parallel to it runs the long Hazen Lake, a hunting paradise which is of importance in the history of the migrations and settlements of the Eskimos. South of this, and again parallel, there follows the zone of depression in the isthmus between Greely Fiord and Lady Franklin Bay. Grinnell Land, which has an ice cap, rises to a height of over 1500 meters. The Archean southeastern part rises abruptly to 600–900 meters (Fig. 70);

FIG. 70—Cape Isabella, eastern coast of Ellesmere Island at Smith Sound in latitude 78⅔° N. (Photograph from D. B. MacMillan.)

the plateaus that adjoin to the west are on the whole lower and in part also bordered by low, narrow plains.

The ice cap of the high Archean plateau in the southeast is more or less continuous near the coast, from which moisture is transported by the Smith Sound winds, and nourishes glaciers (Figs. 71, 72) which descend into the valleys and bays, whereas inland the ice cap has no great extent. At Hayes Sound, one of the fiord branches of Buchanan Bay, the crests rising above the ice streams create majestic mountain scenery. About the central indentation the land is in part uncovered, whereas north of it ice reappears. The 50-meter-high northwestern edge of this ice cap, which runs across mountains and valleys like a wall, called forth Greely's unbounded admiration. In Grant Land glaciation is extremely weak. Traces of former heavier glaciation are lacking in this whole section.

In summer large areas are free of ice and snow. But the summer temperature nevertheless everywhere remains low and, in spite of the great north-south extent, hardly differs from place to place; at Harbor Fiord on the south coast and at the northeastern corner of the island the mean July temperature is exactly the same, namely +3.0° C. The means of the coldest month also do not differ greatly:

at Harbor Fiord −36.8°, in the north −39.6°. The absolute extremes, however, show that the south has greater possibility of warmth both in summer and in winter.

Because of the uniformity of summer, plant life hardly decreases towards the north; on the contrary, Lady Franklin Bay is described as an Arctic oasis in which are united the variety of life forms of the Archipelago and of northern Greenland. Especially do the south-

FIG. 71—Piedmont glacier debouching from the Ellesmere Island ice cap into Baffin Bay. Boger Point, 77½° N. (Photograph from D. B. MacMillan.)

ward-facing terraces permit the vegetation to rise in part to a height of 600 meters (Alpine poppy, *Papaver nudicaule*). Grass grows over wide areas and furnishes pasture for musk oxen. Species of saxifrages form flower beds. The great depressions of the narrow areas are covered with continuous grass and flowering formations. The plateau-shaped heights, on the other hand, are either bare or carry a covering of lichens. In the southern part the vegetation becomes sparser and poorer as one goes toward the west; on the Silurian limestones even the mosses and lichens here become scarce. The total number of species of flowering plants is 115, and the lower plants Simmons estimates to number at least 400 species.

Animal life is abundant in places. This is true of musk oxen as well as of foxes, wolves, hares, lemmings, and bears. The caribou is only a summer visitor and is less numerous. It comes from the west over the ice of the straits and decreases in numbers as one goes north. The coasts are enlivened by many kinds of sea birds, such as guillemots, auks, and eider ducks in many thousands, and in places these make even the barren Silurian limestone soil fertile. Less numerous in species and in individuals are the land birds, such as the snow bunting, the snowy owl, hawks, and ptarmigan. The com-

mon whale does not occur any longer in the southeast and south; it was, however, formerly utilized by the Eskimo in building his houses. This is evident from the ruins at Hayes Sound, which consist more of bones than of stones. Narwhals and porpoises are still to be found.

Ellesmere Island occupies an important anthropogeographic position, namely as regards the migration routes of the Eskimos

FIG. 72—Lateral river of Benedict Glacier, discharging into one of the fiords at the head of Princess Marie Bay, central Ellesmere Island. Heat radiating from the lateral moraine and other exposed rock has created a runway along the side of the glacier through which the melt-water discharges. (Photograph, 1899, by R. E. Peary.)

(see map, Fig. 75). This is caused by its position and characteristic outline—by its position because it connects their original home with Greenland, by its outline because, as a result of the land and sea narrows, it affords relatively the smallest deviation from the coast route. The land narrows were short and low and, because of their vegetation, afforded an opportunity to hunt land animals. The sea narrows can be crossed towards Greenland on the ice. Thus one migration route follows the south coast and runs northwards to Smith Sound, a second goes northward along the west coast to the isthmus between Bay Fiord and Flagler Fiord, a third lies still farther northward and follows Greely Fiord and Hazen Lake, on the shores of which Greely had found house ruins. To the west Sverdrup also discovered traces. The largest former dwelling place is the so-called Eskimopolis on Hayes Sound, with 16 abandoned winter houses.

Greenland*

The Land As a Whole

The History of Its Discovery and Exploration

As a result of its meridional extension through twenty-four degrees of latitude Greenland almost includes the northernmost and the southernmost polar lands. Reaching into the latitude of Norway and Iceland, it became one of the many shores toward which the Norsemen faced and which they colonized. Then, in the age of discovery, lying, as it did, like a bulwark in front of the other American polar lands, it had perforce to be skirted both by the explorers seeking the Northwest Passage and those following the Smith Sound route. Finally, selected anew as a region for colonization, it has become accessible to modern European influences and hence especially to science. Such are the three main characteristics of the history of its discovery and exploration.

Starting from Iceland Eric the Red set foot upon the land previously sighted by his countryman, Gunnbjörn, and from about the year 984 on colonized the southern part of the west coast. Also, to the region north of these colonies, at least in the summer time, seal hunting voyages were made. Nothing was left of these colonies, nor any knowledge of them, when in the year 1500 Greenland was visited by a Portuguese expedition and called "Terra Laboratoris," for a while conceived to be closely connected with Newfoundland. In 1578 it was visited by Frobisher on his third voyage and was called West Frisia. Knowledge of its outline was substantially increased by the three journeys of Davis (1585–1587), who sighted the east coast (Desolation Land) and on the west coast advanced to above 72°; while in 1607 Hudson followed the east coast also to above 73°.

After Inglefield in 1852 had recognized Smith Sound as a strait, the later explorers of Smith Sound and the pole besiegers Kane, Hall, Nares, and Greely step by step unveiled (1852–1884) the whole northwest flank of Greenland. In 1891 Peary began further explorations in North Greenland, and latterly the Danish expeditions of Mylius-Erichsen, Knud Rasmussen, and Lauge Koch have more thoroughly investigated the northwest, the north, and the northeast.

Farther to the south much had already been accomplished one hundred years ago by the German mineralogist Giesecke, who in a seven-year sojourn laid the foundation for the geological exploration of the west coast. Since the middle of the last century local government officials and missionaries have participated more and more, the most prominent among them being Rink. Then expeditions especially sent out for exploration increased, among which that of the Berlin

* Translated by Miss Marion Hale of the American Geographical Society's staff.

Geographical Society under Drygalski (1891–1893) is noteworthy because of its basic study of the inland ice. On the south coast of Disko Island there has existed since 1906 a station for research in all the natural sciences.

The east coast is more difficult to reach than the west coast on account of the ice-bearing southerly current, and the expeditions of the nineteenth and twentieth centuries had to conquer it piecemeal. The beginning was made in 1822 by the Scottish whalers Scoresby, father and son, between latitudes 69° and 75°. Then followed Clavering and Sabine, Graah, the two German expeditions of 1868–1870 inspired by Petermann (the second of which under Koldewey reached latitude 77°), and further supplementary investigations in the region of the great fiords and south of them under Nathorst, Ryder, Amdrup, and Holm from the eighties to the end of the century. The twentieth century brought further progress, first of all in an advance by the Duke of Orleans to latitude 78° 17′ and immediately thereafter with the series of Danish expeditions which Mylius-Erichsen began in 1906 with the brilliant result of closing the gap of 3½° between that point and Peary's farthest on the northern coast, reached on one of his advances from Smith Sound.

Finally, several crossings have been carried out; these will be mentioned below in connection with the inland ice. Thanks to these many-sided investigations our knowledge of Greenland is fuller and more thorough than that of the entire Antarctic.

Size, Form, and Articulation

Greenland, with its 2,180,000 square kilometers, is the largest of the Arctic lands and at the same time of the islands of the earth. From Cape Farewell, situated in 59° 45′, to Cape Morris K. Jesup, in 83° 40′, it measures 2650 kilometers in a south-north direction. Perpendicular thereto it measures about half that length in its central section. In the northern part it has the form of a rectangle and in the southern part that of a wedge, and thus it is an image of the continents, with their broad shoulders in the north and their narrow ends in the south. Like the longitudinal axis, the coasts also favor the meridional direction, the east coast in its northern half, the west coast in its central and southerly part, while in the northwest and southeast the southwest-northeast direction of Smith Sound and of Denmark Strait determines the coastal outline.

This simple general plan is little modified by the major indentations and projections. These consist essentially of broad, open Melville Bay and of Hayes Peninsula stretching between it and Kane Basin, furthermore of the long projection of Prince Christian Land (Northeast Foreland) opposite Spitsbergen, and finally of Peary Land, half-

attached, as it were, to the northern coast. In contrast, detailed articulation occurs throughout almost the whole circuit of the coast; only Melville Bay with its unbroken ice front and the basaltic portion of the coast on Denmark Strait have more regular lines. Elsewhere, numerous transverse fiords or broad bays penetrate far inland, the largest being in the central section both of the west and of the east coast. Lowlands and flat coasts only are of subordinate importance throughout. The interior is occupied by the flat-domed upland of the inland ice, and the border zone either by the ice cap edge or by plateaus and mountains into which the sea enters on one side and on the other frequently the inland ice penetrates in the form of ice tongues discharging through deep fiord valleys.

Geological Development

Under its ice cap Greenland is in the main an Archean peneplain. It is bordered by zones of sedimentary and volcanic rocks, the former for the most part horizontally stratified, and in the north is flanked by a series of folds. In the coastal zone the sedimentary formations, where they appear, often give way to the basement rock before the edge of the inland ice is reached; the sedimentaries themselves are chiefly coastal deposits. Greenland is, accordingly, a very old, persistent land mass, which was subjected to frequent transgressions of the sea on its borders only. The leading rocks of the border zone outcrops as well as of the morainic material originating in the interior are gneiss and granitic gneiss and, in the extreme south, also granite. The whole is an eroded remnant of the Huronian mountains folded in pre-Silurian time. In the first half of the Paleozoic the gneiss surface in the north, where its position is especially low, was subjected to the same transgression of the sea that to the west affected the Arctic Archipelago. These deposits were then involved at the extreme northern border in the Caledonian folding. An immense structural axis thus links the British Isles and Scandinavia across Spitsbergen and the submarine ridge with northern Greenland and Ellesmere Island (Fig. 2 on p. 109, above) and bridges the widest gap that exists today in the circumpolar lands. On the remaining coasts of Greenland the sedimentary deposits lie practically horizontal: in westerly middle Greenland the Cretaceous and Tertiary, in northeastern Greenland older and younger formations than these. Here faults play an important part.

The Tertiary period was marked by basalt outpourings. In East Greenland may be differentiated a northern and a southern basaltic region. The latter is the most compact and occupies the same latitude (about 70°) as that of West Greenland. It is possible that both are joined under the inland ice and are continued by way of Ice-

land towards Europe. In this basalt zone there is also noticeable a depression which is reflected in the height of the border mountains as well as that of the inland ice. By this zone a northerly gneiss peneplain is thus separated from a southerly one. At both ends of the depression there is the maximum development of inland ice drainage in the form of outlet glaciers.

In the Tertiary period Greenland had a warm climate with a luxuriant forest vegetation, to which fossil poplars, chestnuts, oaks, laurels, walnuts, and magnolias testify. It was brought to a close by the geological age to which Greenland owes the controlling principle of its present conditions: the ice cap which covers 95 per cent of the land was formed in the Pleistocene. It was then still thicker and more extensive; around Disko Island erratics lie up to an elevation of 1800 meters. But the theory that Greenland was then entirely covered by ice is disproved by the many sharp peaks which tower above the rounded forms in the border zone.

FIG. 73—Geological sketch map of Greenland.

After the Glacial Period the land was subjected to lesser climatic changes. Above all, however, the postglacial period was accompanied here also by a lowering of the sea level. Traces of this occur at various elevations, with a noticeable increase of the amount from south to north of from 50 to over 500 meters. Submerged houses point to a recent reversal of the movement on the west coast.

Surface Configuration

The inland ice gives Greenland the almost perfect form of a flat shield. Its configuration is based on the laws governing a viscous mass with a central area of accumulation and a marginal discharge. Along the line of the meridional axis the elevations are mostly between 2500 and 3000 meters. Nowhere in the center is there a place where bed rock appears above the surface of the ice. About 100 kilometers from the southeastern edge, however, rise the high moun-

tains of "Schweizer Land," and about 50 kilometers from the northeastern those of Queen Louise Land. A deviation from geometric regularity nevertheless exists in the fact that the longitudinal axis of the ice cap carries two summits and, in its southern part, moreover, is shifted eastward a considerable distance away from the median line. It is therefore evident that the ice shield, even though on the whole it determines its own configuration, is not entirely independent of the substratum. It is in the higher mountains to the east that lie the backbone of the ice and its center of dispersal, as was first clearly recognized by von Drygalski and confirmed by De Quervain.

On the west coast, in the middle latitudes, there is an independent mountain system which is not reached by the inland ice and which has only a few ice caps of its own but which is cut up by long, branching fiords that drag the edge of the inland ice down into the sea. North of latitude 69°, instead of narrow fiords, wide bays cut into the land; these receive large masses of the inland ice, while the larger peninsulas and islands between form independent highland ice caps. Here, on Disko Island, Nugssuak Peninsula, and farther north, ice-

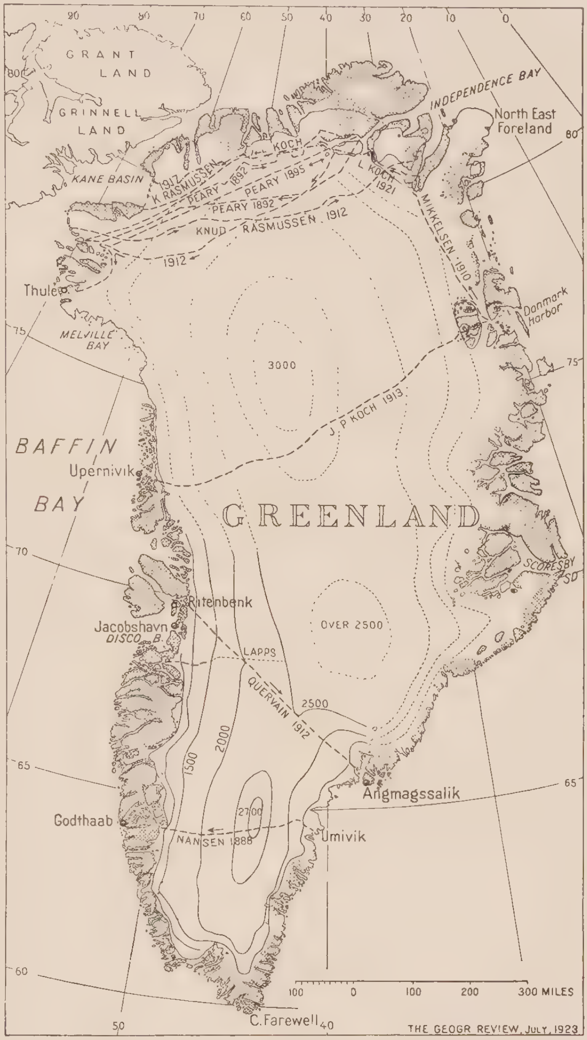


FIG. 74—Map of Greenland showing the general topography of the inland ice, after De Quervain (elevations in meters). Scale, 1:21,000,000. The stippled areas are ice-free. The routes of explorers crossing the ice sheet are also shown.

free coastal cliffs tower 2000 meters high and more, while to the east, in the transverse depression, the edge of the inland ice lies at an elevation of only 500 to 600 meters. At the same time the great bays, by their deep incisions into the ice cap, produce great outlet glaciers (see Fig. 78). On the west coast the ice-free belt dips toward the inland ice, while on the east coast it rises toward it. Still farther north the independent highland ice of the west increasingly coalesces with the inland ice, until from the northern part of Melville Bay onward no particular difference longer exists between west and east. Along the north coast large ice-free surfaces again appear, especially the only slightly ice-covered Peary Land—an indication that here the inland ice, on account of less nourishment, no longer has the power it has farther south.

In the marginal belt the ice, pierced by an increasing number of nunataks, as the ice-free protuberances are called, changes from the form of a cover to that of broken-up inlays because of the fact that the plane of its descending surface cuts obliquely across the surface of the exposed terrane (Fig. 86). Thus, against the broad flat dome of the inland ice is set a narrow border of more varied scenic aspect. This strip, partly ice-free, partly covered with local glaciers, has varying widths, from 0 to more than 150 kilometers. It is dominated by four types of landforms. The most extensive is hummocky rock topography. This type is precipitously trenched by deep valleys and fiords but is undulating and rounded on its upland surface. In the numerous shallow depressions lakes accumulate which, to be sure, exist only a short time during the year but nevertheless are of much importance to the fauna and flora and are especially characteristic of the summer landscape. This, namely, is the region of Pleistocene glaciation; its smooth forms have been produced mainly on Archean but also to a certain extent on sedimentary rocks. To it belong mainly the lower hills; in central West Greenland the land, even at a distance of 100 kilometers from the present border of the inland ice, may have been covered with ice up to a height of 1000 meters. Above the hills often tower high serrated mountains, rising on the west side to 2000 meters and on the east side to 3000 meters in elevation—alpine forms which even in the Glacial Period remained uncovered. These constitute the second type. The trap rocks are responsible for the third type, especially on Disko Island: high, steep, often terrace-bordered plateaus, with a uniform, slightly dissected upper surface, crossed only by shallow valleys. The fourth landform type consists of the old moraines, strewn sparingly, it is true, over the rocky landscape, but often rising abruptly above it as much as 50 meters and with their dense vegetational covering standing out from the bare rocky hillocks.

On all sides appear the phenomena of solifluction and rock weath-

ering, the latter favored by the rapid mechanical disintegration especially of the younger volcanic rocks and the recurring summer seepage of the melting ice. In spite of the thaw the rivers are unimportant, as, on account of the narrowness of the ice-free strip of land and the encroachment of deep fiords, very little space is left for their development. The many short streams have for the most part steep gradients. Fiords as the characteristic bay formation of Greenland occur within all the landform types; but, nevertheless, they vary in detail—in the gneiss mountains they are long, narrow, and at right angles to the coast; in the sedimentary regions, on the other hand, in the east as well as in the west, they are much wider and less regular. Their direction depends often on the strike of the gneiss and often on the occurrence of fissures or faults.

Climate

Because of its inland ice Greenland constitutes a separate climatic region and an independent center of action. There is developed a pressure gradient toward the seas on both sides of it; over these lies lower atmospheric pressure. Depressions have their paths along Davis Strait and past Iceland. These determine the winds on Greenland's coasts, not only in their temporary changes but also for longer periods of time. Between the wandering depressions Greenland lies like a stable wedge. Occasionally it is swept by them itself, but generally only at its southern end. The normal condition is a descending current of air from the margins towards the depression troughs over the ocean—on the east coast as a northwest wind and on the west coast as a southeast wind—which has been observed to extend up to great heights. Beginning with the second German North Pole expedition, all observations fit into this picture; and Peary compared the wind, in respect to its unchanging radial direction and its steadiness, with the run-off of the water from the high interior towards the coast. The descent gives the marginal winds the character of föhn winds. If the low pressure and wind régime of one side spreads over the whole inland ice, then "complete föhn" (De Quervain) reigns supreme. Of more frequent occurrence, however, is the "double föhn." From a central cold area the temperature rises towards both sides by jumps of almost 10° C. in a distance of about 175 kilometers from the border of the inland ice. The relative humidity is quite high (over 80 per cent) and constant. The total yearly evaporation probably amounts to 50 millimeters, the total precipitation to about 400 millimeters. In the interior and in the north the snow is almost constantly scudding over the surface up to knee height, and when the winds are strong it may be whirled up to a height of 30 meters.

In the ice-free marginal belt clouds, fog, and precipitation are

greater; and the velocity of the wind is much decreased. The temperature in summer rises noticeably immediately in front of the ice border. Within the ice-free zone the temperature differs between the sea border and the inner border. In spring and summer the interior of the fiords is somewhat warmer than the outer coasts, in winter the reverse is the case. The differences sometimes amount to 5° and more, and even the mean temperature from May to July is about 1.5° less on the outer than on the inner side, e. g. in Godthaab as compared with Kornok. In the interior of a fiord the summer heat may become oppressive, the vegetation develops a more continuous cover, and berries ripen in greater quantities than on the outer coast, where the cold ocean mists have a restraining effect. Thus even in this narrow strip of land the universal contrast between coast and inland conditions is noticeable. In summer, on the border between land and sea, a small monsoon-like system, according to De Quervain and Wegener, injects itself into the major system of offshore warm föhn winds. It is these winds, i. e. the sea winds, that in summer lower the temperature on the outer coastal border. But the decreasing force of the föhn also plays a part. Before the ice edge there lies consequently a veritable dry belt, with much curtailed precipitation, saline lakes, such forms of arid topography as toadstool rocks, and loesslike soils. Even within the fiord zone the föhn influence may diminish 10° and more. The föhn is most effective in winter: then it raises the temperature at times from –20° C. to considerably above the freezing point and interrupts the bracing winter cold with its fatiguing and enervating effect. Even in Smith Sound this was experienced by Kane and Nares. Throughout Greenland, therefore, the absolute temperature maxima of the winter months are noticeably high (Godthaab in December, 15°), and the temperature fluctuations and changes are then very large, while in summer they are small.

	N. Lat.	W. Long.	Average Temperature (C.)			Absolute Extremes (C.)		Precipitation (mm.)	Frost Days
			Feb.	July	Year	Max.	Min.		
Ivigtut	61° 12′	48° 11′	– 7.5°	9.7°	0.5°	23.4°	–28.9°	1170	208
Jakobshavn	69° 13′	50° 55′	–19.0°	7.7°	– 5.7°	19.4°	–42.0°	215	256
Upernivik	72° 47′	55° 53′	–22.8°	5.0°	– 8.7°	17.8°	–40.4°	235	290
N. W. Greenland	82° 0′	63° 45′	–37.5°	3.2°	–18.8°	10.5°	–52.1°	100	(295)
Danmarks Havn	76° 46′	18° 30′	–27.4°	4.4°	–12.6°	17.1°	–40.9°	145	
Angmagssalik	65° 37′	37° 16′	–10.8°	6.2°	– 2.2°			930	

The local temperature differences are great between the north and south in winter. The southern point of Greenland is then strongly under the influence of the low-pressure areas over the ice-free seas, whereas the north experiences to the full the climatic effect of the ice-and-snow-covered land and the ice-girded coasts. The mean Feb-

ruary temperature decreases pretty uniformly along the coast from $-7.5°$ at Ivigtut to $-37.5°$ at Smith Sound. On the contrary there is little difference in the summer heat over the whole of Greenland. For the southern end scarcely attains a July average of 10°, while even in the farthest north there is no place that has an average below freezing in the warmest month. Thus also in the north plant and animal life can develop in comparative profusion in the short summer, especially as the snow cover that has to disappear is not considerable.

In spite of the small regional differences in summer temperature two traits stand out as noteworthy. In the first place, the west coast around Disko Island has a higher summer temperature than that around Godthaab, 5° of latitude farther south, because the East Greenland Current, bending around the southern tip, brings ice from the east to the southern part of the west coast. This condition was set forth as long ago as the "King's Mirror," an Icelandic work of the mid-thirteenth century, and sailing directions were given accordingly. Secondly, the contrast between the east and west coasts appears increasingly as one goes south because in summer the sea winds blow over open water in the west, while in the east they blow over floating ice.

In precipitation the tapering end south of latitude 66° stands out rather sharply from the rest of Greenland. There alone is precipitation high—in Ivigtut almost 1200 millimeters. In the north downright aridity prevails. In the southwest the humidity and the long-continued melting of the snow contribute to the lowering of the summer temperature. The ground moraines of the slopes then often begin to flow.

The Plant Cover

The coasts of Greenland viewed from the sea present the aspect of bare or snow-covered rocks. Only at close quarters does their plant covering become visible. For, in the first place, the vegetation retreats from the cold, foggy, and wind-exposed outer margin to the slopes within the fiords. Furthermore, the plant formations seldom attain a dense and tall growth, trees being limited to dwarf varieties and the vegetation consisting chiefly of shrubs, herbs, and grasses, as well as mosses and lichens. In places they form only a thin covering or grow in open stands. The plant cover contrasts even less distinctly with the bare rock when the color of the leaves and flowers or of the dead stalks and branches chances to correspond with the tones of the rocks. "Scarcely anywhere in Greenland," say Payer and Copeland, "does the plant world succeed in entirely altering the general color of the soil as based on the kind of rock from which it is derived; at the most it is able to tinge it. Mosses, lichen, grayish

green grasses, ranunculus, saxifrage, etc., form separate scanty colonies in the weathered rock crevices. In lieu of forests there are birch bushes here and there a few inches high (the stems of which are often no thicker than a match), also bilberry bushes that are no higher, but more often willows that trail along the ground and have rootlike branches. It is a result of the months-long polar day that elevation as a factor of vegetation growth makes itself felt less than in Europe, where the character of the vegetation changes noticeably with every 300 meter increase in elevation. We found also almost every species of the plain, especially the poppy, on mountains 500 to 1000 meters high. On one rocky peak 2300 meters high grew a long, fibrous kind of moss in addition to the well-known black and yellow lichens which one meets everywhere in the European Alps as the last representative of vegetation." There are also, to be sure, on the larger plains, exceptions to this generally scanty covering.

The vegetation is most luxuriant and of greatest variety in the ice-free, warm, southerly end with its abundant rainfall. Here, especially between latitudes 60° and 62°, grow Greenland's "forests" (Fig. 81), consisting of five varieties of arboreal growths. The stands are open, also as a rule low and stunted, though in some cases they may form thick copses, attain a height of more than 4 meters, and have a vertical range up to 150 meters. Indeed, the dwarf juniper (*Juniperus communis*) appears in profusion at heights of over 300 meters, and it does not shun the outer coast. Associated with these woody growths is a no less luxuriant shrub and herbaceous flora, and in the clearings carpets of grass appear.

With increasing latitude the timber grows to a less height, and individual species drop out, principally the birches. The willows, however, represented chiefly by *Salix glauca*, extend as far as 73° in the form of bushes half a meter high; and many species, lying prone on the ground, persist to the northernmost coast. Towards the middle latitudes bush and meadow formations predominate. They consist of willows, grasses, shrubs, herbs, bracken, and mosses of a great number of species and with a wealth of brilliant flowers. Another formation is the brown heath, consisting of dwarf bushes like the crowberry, the juniper, rhododendron, and others, and also of mosses and lichens. Besides these bush heaths moss-covered swamps, composed of but a few species and usually having a cushiony and eneven surface, occupy large areas. They are associated with stagnant water, which is abundant on the upland undulations as well as in inundated areas, and in summer they are the swarming places of mosquitoes. Frequently also the hummocked rocks of the gneiss region are covered with only a few kinds of lichens, especially the knoblike, black *Gyrophora hyperborea*, which lends a somber aspect to the evenly rounded landscape. The fell formation, which extends through the whole of

Greenland, is in the main composed of these and other kinds of lichens. The higher vegetation often protects itself against the drying effect of the föhn by frequenting the moister habitats and the sheltered lee of boulders, which circumstance may bring about a linear arrangement of the vegetation.

As far north as Disko Island all these formations continue in their luxuriant development. Sturdy man-high willow bushes, thick carpets of moss, colorful orchids, lungwort shrubs one to two meters high recall the vegetation of southern Greenland; especially is that so on the mild south coast of Disko. But farther north bushes, meadows, heaths, and marshes shrink to small patches; and the rock vegetation of isolated bushes, shrubs, mosses, and lichens predominates, between which the ground appears and determines the coloring of the landscape. Many species have their northern limit at Disko.

The type of growth that develops north of Disko appears also on the farther side of the icy wastes of Melville Bay, around Smith Sound. Tall growth and thick covering no longer occur; but the 136 species existing there, including the willow (*Salix arctica*), in the variety of color of their close-set flowers still bring forth a small paradise in this Arctic region.

Not essentially poorer than the vegetation of northwest Greenland is that of the northeast, whence the *Danmark* expedition brought home nearly 100 flowering plants. In general, north of the latitude of Disko Island the two coasts differ but little in the number of their species within stretches of corresponding length. In the latitude of Disko the east coast also attains relatively high development (176 species), because here, in the region of Scoresby Sound, favorable, ice-free soil exists to a greater extent than farther south. On the other hand, the southern half of East Greenland is far behind the west coast, which in places has nearly 250 species. The limited ice-free surfaces and the lower summer temperature, already mentioned, explain the unfavorable conditions of the east coast. In the extreme southern end the contrast between east and west vanishes; here are found together almost three fourths of the 400 higher plants of Greenland.

The question arises, What relation does the present flora bear to the Glacial Period? According to Nathorst no plants survived the Glacial Period; all species have migrated either from Europe or from America. On the other hand, Warming and others hold the view that the alpine flora of Greenland has in no small measure survived the Ice Age and has only been supplemented by migrations. Certainly very many summits of the marginal belt were not covered by the ice even at its greatest extent. Just as today the rocks and nunataks may be warmed to as much as 40° C. and the shallow stagnant pools near the inland ice to 15°, they could have been warmed to similar temperatures even at the time of the maximum extent of the ice sheet,

and they may have offered a place of refuge to many species. The present-day flora shows marked relationship with Europe as well as with America, yet recent investigations seem to indicate more and more the greater importance of the connection with America.

The Animal World

Like the flora, the fauna, in so far as it does not belong to the sea, is confined to the ice-free coastal borders, only not quite so narrowly, for even in the middle of the inland ice Koch came across foxes and two species of birds. But, while the flora of the northerly half of the coasts is represented by less than half as many species as that of the south, the larger mammals show no such decrease, the number of species being greater in the north than in the south. In northern Greenland still they find sufficient pasture and at the same time security from mankind, and thus it is that only recently several species have crossed over from the Archipelago on the ice bridges of the straits. The southern fauna may, therefore, be classified with Vanhöffen as endemic. Reindeer, fox, and hare live almost everywhere in the ice-free coastal lands, while in the north and northeast there are in addition the lemming, musk ox, wolf, and ermine. For the time being these migrants have found a limit on the west coast in the ice of Melville Bay and on the east coast in that of Scoresby Sound.

The reindeer (*Rangifer tarandus*) lives in almost any place where it can find large enough pastures in the ice-free border. It is of manifold use to the Eskimo. Through the introduction of firearms its numbers have become greatly reduced. Before 1850 14,000 skins were exported yearly; since 1860 the annual exportation has often been less than 1000. The polar wolf has entered the region but recently, and from the accounts of explorers it seems possible to follow its course by way of the north to the east coast since the seventies. Likewise the musk ox, according to Nathorst, has but recently reached East Greenland. It must, however, at a remote time have lived there once before.

The mammalian fauna in the sea and upon the ice around Greenland may also be divided into a northern and a southern group. Only the fiord seal inhabits the whole circumference. To the fauna of the south belong the hooded seal, Greenland seal, humpbacked whale, bottle-nosed whale, finback whale, and swordfish; to that of the north belong the Greenland whale, narwhal, whitefish, walrus, bearded seal, and polar bear—the last two of which, drifting on floes, also reach the southerly region. With them, therefore—just contrary to the land animals—the northern is to be considered the endemic group and the southern the immigrant. The hooded seal and Greenland seal are apparently drawn by the East Greenland Current from the waters of Spitsbergen.

By far the most valuable of all Greenland's animals, whether of sea or land, is the seal. It occurs in five species, of which the fiord seal (*Phoca foetida*) is the smallest but the most widespread and numerous and therefore also the most important. It provides nourishment, clothing, fuel, and light, and a covering for the kayak. It inhabits the fiords as well as the outer coast but prefers ice-filled waters. It is caught either on or under the ice or by the use of the kayak. The number of skins obtained has many times been more than 100,000 annually. For the most part they are used in Greenland itself. Of the whales, the largest is the Greenland whale (*Balaena mysticetus*), which reaches a length of over 20 meters. It has already become scarce as far north as Smith Sound. In this region the walrus lives in great herds. Along uninhabited stretches of the coast the polar bear wanders about, preferring the ice to the land or the water. In their legends the Greenlanders recognize him as their master teacher, as to food, wanderings, and methods of hunting. Like the Eskimo, the polar bear finds his chief food in the seal and has berries for his dainties; he travels extensively, climbs ice hummocks as a lookout, and stalks his prey; and in the same way that the she-bear makes a snow cave for her young the Eskimo builds his snow house.

In its composition the piscifauna shows the influence of the ice, to the extent that neither the more southerly American nor the Norwegian forms have entered the region because the water around Greenland's coasts, in spite of the warm admixture on the west coast, is not sufficiently warm. The number of species, a round 80, is therefore comparatively small. Halibut and sharks prefer the waters in the vicinity of icebergs; these two are the most important for the Greenlander. Of fresh-water fish there is mainly the salmon, living in the ponds and pools.

The water, the ice, and the coasts, but principally the coasts, are all inhabited by flocks of birds. "Warmly feathered and light of wing, the birds are better prepared than all other vertebrates for life on the ice-bound coasts of Greenland," says Vanhöffen. "They are circumscribed neither by broad fiords nor precipitous, inaccessible cliffs, neither by crevassed glaciers nor the inland ice. Even two land birds, the ptarmigan and snow bunting, have been met with at the most northerly point reached by man, in latitude 83° N.; and on the inland ice Nordenskiöld found ravens and Nansen the snow bunting." The ptarmigan, which is killed for its feathers, is distributed abundantly and uniformly over the whole ice-free border. Numerous also are the snowy owl, snow bunting, hawks, and ravens; and also species of gulls, the fulmar, and the eider duck, whose down is gathered on low-lying islands. All are birds of passage; they flee the cold winter by migrating either to southern Greenland or far away.

As regards the lower fauna the latitude of Disko Island forms a

dividing line in western Greenland. To the north of it fewer species of insects live than south of it, and earthworms and land snails are entirely lacking. To the south of Disko Bay the ice-free belt is broad; to the north, very narrow. The proximity of the inland ice is detrimental to the small-animal life because of the cold and occasionally because of the warm föhn winds which in summer dry up the vegetation and in winter blow away the protective snow covering. North of Melville Bay, therefore, there is a second division, as here an ice-free strip of land again appears and makes room for new small-animal life. The same contrast may exist between the east and west coasts; at least the swarms of mosquitoes are not so considerable on the east coast as on the west. Of the mosquitoes of the west coast in summer De Quervain says: "As soon as the wind goes down or the rain stops they break forth in swarms from behind every lichen, from behind every tuft of grass, and descend greedily upon us."

Reptiles and amphibians are entirely absent from Greenland's animal life.

Man

Greenland is habitable in its ice-free strip where this is sufficiently broad and continuous to furnish varied hunting grounds in the form of bays, peninsulas, ice, and open water; for human life is dependent upon the two great groups of mammals, and on the whole more upon that of the water than that of the land. In addition to these, fish are the most important, birds least of all.

The early colonization of Greenland raises two questions: how man came to the country and in which direction he encircled its coasts (Fig. 75). The first finds an answer in the narrows of the Smith Sound-Robeson Channel strait. From the Barren Grounds the way leads through Boothia Felix, Devon Island, and Ellesmere Island with alternating land and ice bridges to this strait, which can be crossed at several places. The migration by this route may have been in pursuit of the musk ox, which still extends over the whole Arctic Archipelago as well as the northern and northeastern borders of Greenland. It is a matter of record that as late as the sixties Ponds Inlet Eskimos crossed over and joined the Etah Eskimos.

Now, how have the Eskimos of the northwest corner attained their peculiar distribution? Even at the present time Eskimos live on the west coast from the southern end to the commencement of Melville Bay; then on Smith Sound as an isolated branch, the Etah Eskimos; and on the east coast just below the Arctic Circle, at Angmagssalik—i. e. in three separate districts (Fig. 10). After the discovery of the Angmagssalik Eskimos Rink and Holm propounded the theory that they may have come there by way of the north, and the route of the musk ox supports this theory. Later Isachsen was in-

clined to assume this route for the West Greenlanders also and set Melville Bay aside as impassable. Now, however, Mylius-Erichsen and Rasmussen have found numerous traces of Eskimo visitations along the whole extent of Melville Bay, which proved passable with sleds, while such traces are lacking in the northwest from a little north of Humboldt Glacier. Rasmussen, therefore, believes that colonization took place only by the southern route. On the other hand, at the time of their discovery the Etah Eskimos had no knowledge of their more southerly neighbors; and recently in northeastern Greenland discoveries of ruined dwellings and tent rings are increasing that make it appear that settlement along the musk ox route took place in the form of sudden advances and forward thrusts at different intervals.

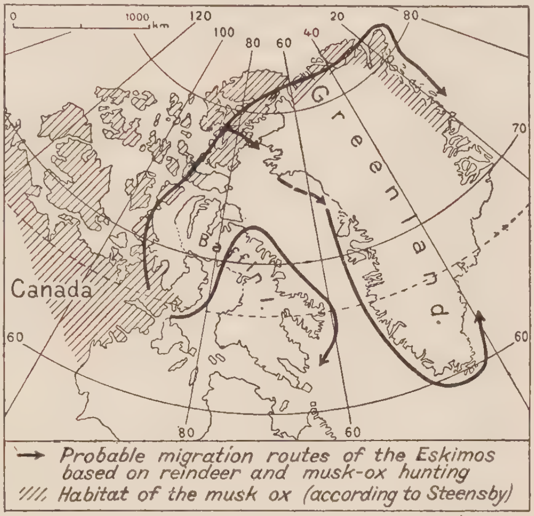


FIG. 75—Migration routes of the Eskimos. Scale, 1:55,000,000.

Accordingly, at the present time both routes are under discussion. Schultz-Lorentzen accepts both and lets them meet at Godthaab, while recognizing linguistic and ethnical differences on both sides of this point and correspondence between the southern group and that of Angmagssalik. Thalbitzer and others assume a blending of north and south elements in the Angmagssalik Eskimos. In particular their kayak points to the south. At any rate, everything considered, the whole circumference of Greenland appears to be involved in these wanderings; and in many regions an overlapping of different waves and periods of migration appears to have taken place in one direction or another.

When the Norsemen arrived no Eskimos dwelt in the southerly part of the west coast. Ruined dwellings and fragments of utensils, however, pointed to their earlier presence there. The newcomers settled on the southwest coast and for centuries constituted the entire population, divided into the two colonies of Österbygd (near Julianehaab) and Vesterbygd (Godthaab), where there may have been perhaps 2000 settlers. From here they also made incursions upon the American mainland and there became acquainted with the Eskimos, whom they called Skrälinger. In the fourteenth century

the Eskimos on the west coast of Greenland proceeded farther south and perhaps had hostile encounters with the Norsemen. In the fifteenth century the Norse colonies' connection with the motherland ceased, and the colonies finally disappeared either because their population succumbed in battle or because it was assimilated by the Eskimo inhabitants, who were better adapted to the environment. At any rate, an early star of Scandinavian colonization in the New World vanishes silently and without a trace in the darkness of the Middle Ages.

A new period of European colonization begins with the missionary Hans Egede, who settled in Greenland in 1721 to search for descendants of the Norsemen and to convert the Eskimos. He reëstablished a Greenland trading company in Bergen such as had already existed in the seventeenth century and, most important of all, founded the first Danish colony in the neighborhood of the present Godthaab. From this point Danish colonization spread to the north and south. Until the time of the World War only the west coast up to Upernivik and the east coast up to Angmagssalik were recognized as being under Danish suzerainty. In 1916, when Denmark ceded its West Indian possessions to the United States, the latter concurred in the extension of Danish control over the whole of Greenland. Norway lately protested against the extension of Danish sovereignty to the northern part of the east coast, and on that account a convention was concluded in 1924 between the two nations granting trading, sealing, and other hunting and fishing rights there to Norwegians.

The land is ruled by a small Danish official staff. Less than 300 white people live in Greenland. The sixty-two communities into which the west coast is divided are directed by natives. These communities are grouped into twelve districts: Julianehaab, Frederikshaab, Godthaab, Sukkertoppen, Holsteinsborg, Egedesminde, Christianshaab, Jakobshavn, Godhavn, Ritenbenk, Umanak, and Upernivik. In addition there is Etah, the site of the isolated Polar Eskimos; as well as Angmagssalik, the only colony of the east coast until the establishment in 1925 of a new colony on Scoresby Sound.

Egede once estimated the population at 30,000, perhaps led into error because of the many uninhabited houses. It could hardly have amounted to more than 10,000. In the course of the nineteenth century it has doubled (in 1805, 6,000; in 1900, 11,100; in 1921, 14,350). The influx of epidemics which formerly followed after the visit of a foreign ship has been prevented by the government's monopoly on commerce and the strictest hygienic supervision of arrivals. The rate of population increase by birth of 4 per cent is also a factor of consequence, though it appears to have grown only by race intermixture, as the fertility of the pure Eskimo is always recorded as small. At the present time, on account of this increase, the saturation point has been

reached. Perhaps some further colonizing possibilities still exist on the east coast. Primarily, however, the Danish government has devoted itself to economic improvement through attempts at cattle breeding, better organization of the fisheries, and the like.

From the increase in population there has also come about a change in the type of population. The 6000 inhabitants of one hundred years ago were Eskimos, the 14,000 of today are "Greenlanders"—as

FIG. 76—Eskimo summer camp on Raeve Island near Egedesminde, western Greenland. Women and children wearing sealskin clothing; the tent is also made of sealskin. (Photograph by Arnold Heim in his and M. Rikli's "Sommerfahrten in Grönland," Huber & Co., Frauenfeld, 1911, p. 69.)

they call themselves with the well-known pride of half-breeds. Only the isolated Etah and Angmagssalik Eskimos are still pure, but they constitute but 7 per cent of the population. The mixed race of Eskimo and European blood makes a fine type physically, with its large black eyes and its brownish skin color resembling that of the Mediterranean peoples. Fundamentally the race, hardened by battling with nature's severity, is sound and strong. The least vigorous children die in the early years without being kept alive by science. Under certain circumstances they are even drowned by the parents themselves. Nevertheless, nervous diseases, even extreme hysteria, occur among the northern and eastern Greenlanders, possibly induced by the excessive consumption of meat. The Greenlander also has the cheerful, quiet temperament of the Eskimo race. He is calm, patient, genial, and companionable, slow of speech but, when narrating, lively in gesticulations.

The settlements consist of an intermixture of primitive, low stone and turf houses with some wooden buildings. They are only winter settlements. In summer the inhabitants set forth for the seasonal hunt and lead a camping life (Fig. 76). But dwelling places have, at all events, become more permanent than formerly; by means of churches, schools, and trading posts the population is being weaned from its roving. At the same time European cultural necessities have been introduced. Here and there oil lamps have been replaced by stoves, skins by feather beds. Tobacco and coffee are widely used, the latter in large quantity and frequently. Alcohol, at least officially, is not distributed. Newspapers appear in the Eskimo language, and there are

Average Annual Number of Animals Killed in Greenland, 1910–1920

	Reindeer	Fox	Walrus	Whitefish and Narwhal	Seal	Shark
North Greenland	150–300	500–700	60–150	600–1100	60,000–80,000	28,000–35,000
South Greenland	1900–2800	1600–2600	—	70–900	20,000–45,000	5,000–12,000

but few illiterates. Many persons agree with Nansen in seeing in these changes a loss of the original virtues. Perhaps, however, the Greenlanders could no longer exist independently, as their traditions and standards and the consciousness of their worth have been gradually undermined by European rule, economy, and religion. For all that, in many things they still follow their unwritten laws, based on the fundamental principle of mutual assistance, e. g. in the division of certain spoils of the chase.

In their economic life the kayak and the dog sled are irreplaceable, while the women's boat (umiak) used for long journeys is becoming obsolete. The kayak, indeed, is less a vehicle of transportation than an instrument of the chase. In the south, where the sea remains open, the livelihood of the Greenlanders lies on the outer coast and is based upon the kayak first and foremost. Therefore the mortality is greater here than in the north, because hunting sea animals in the variable winter weather of the south is particularly difficult and often accompanied by accidents. In the north the bays and coastal waters are covered with solid ice. Here the dog sled is the basis of transportation and livelihood. The Greenland dog is a runner of the greatest endurance and can lie out of doors without protection in the severest winter weather. The importation of dogs is prohibited so that the strength of this indispensable race may not be impaired. The chief object of the hunt in the north as also in the south is the seal—in the north chiefly the fiord seal (*Phoca foetida*), in the south *Phoca groenlandica*. In the north the seal is hunted from the ice when sunning himself (the *utok* method), in the south on the open sea from the

kayak. The predominance of the seal among the animals hunted is clear from the table above. From 1916 to 1918 there were yearly exported an average of 30,000 sealskins and 1,355,000 kilograms of fish oil.

The Individual Regions

In Greenland, if anywhere, a division into a central region and marginal regions is called for. From the standpoint of human geography the marginal regions deserve the greater attention. From the standpoint of physical geography the central region is of dominant interest, not only because of its immense size and the grandeur of its phenomena but also because of its preponderant influence and its encroachment on the marginal regions, where the ice is everywhere the fundamental factor. "Whether we observe the life and activity of the inhabitants, the utility and distribution of the animals and plants, the quality of the soil and the form of the rocks, or the variations of the climate, we always find that the ice has affected them, now and in earlier times" (von Drygalski).

The Inland Ice

Interior Greenland has been compared with the Sahara. The parallel applies in many respects: in the uniformity of the shape and character of the surface, the lack of every sort of life, the large daily range of temperature, the bright sky, the dry, sandlike granular snow, and the importance of the wind as the force that drives the snow and, as in the desert sand, gives it form. The importance of this force with regard to North Greenland in particular has been emphasized by Peary, who has vividly described its effects there. Only towards the borders does temperature in addition to wind contribute essentially to the development of minor forms; and all the phenomena associated with melting develop there, such as lakes, brooks, even large rivers, snow marshes, and small melt-water holes lying close together. The major forms of the ice, however, obey other laws. Neither wind nor temperature are determinant in their case, only the internal nature and movement of the ice itself as well as the horizontal and vertical configuration of its floor. Shield form, breaking off in steps, and crevassing are the outstanding important elements.

The inland ice is a carapace which in the larger features of its outer edge repeats the outline of the land, bending back, for example, at Melville Bay and projecting in broad lobes at Hayes Peninsula. The ice sheet rises gently from the sides towards a central north-south divide. This divide, as has already been stated in the general survey, lies to the east of the median line, i. e. towards the higher mountains that constitute the principal source of supply of the ice. A serrated mountain region, which rises to a height of 3400 meters, lies close to

the east coast about on the Arctic Circle. Only in the latitude of Melville Bay does the divide shift to the middle or even a bit west of the middle.

On several routes profiles have been laid across the ice cap (Fig. 74). After shorter advances had been made by Adolf Erik Nordenskiöld and by Peary, Fridtjof Nansen in 1888 first succeeded in crossing the inland ice, here in latitude 65° about 560 kilometers wide and with a culminating height of 2700 meters. Then in 1892 Peary crossed the ice in the far north from northwestern Greenland to Independence

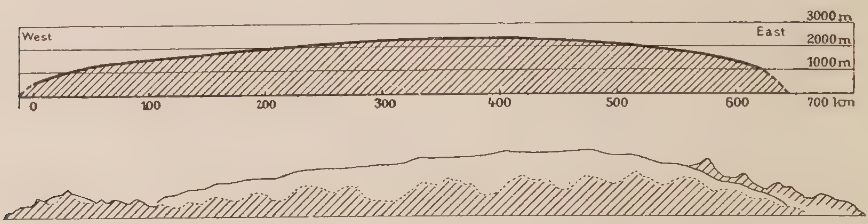


FIG. 77—Profiles across Greenland along De Quervain's route (see Fig. 74) from latitude 70° on the west coast to latitude 66° on the east coast. Vertical exaggeration, 200 times. The upper figure is, excepting for this exaggeration, drawn to scale. The lower figure is a schematic profile showing the probable relation of the ice cap to the substratum and the descent of the cap in broad steps.

Bay and back. Finally three crossings were carried out in the years 1912–1913. Alfred de Quervain made a very exact cross section 650 kilometers long from Disko Bay to Angmagssalik, which surmounted the ice divide in 2500 meters. J. P. Koch and Alfred Wegener went from the east coast in a higher latitude to Upernivik over the highest yet recorded part of the divide, viz. 3000 meters. Knud Rasmussen and Peter Freuchen made a traverse from Cape York northeast to Peary Channel and back and encountered a height of over 2000 meters. The contour map derived from these inland journeys shows that the profile of the divide has a number of convexities and concavities.

The descent to the east and west is very gradual in the interior and becomes steeper towards the borders. The ice is characterized by step surfaces that are probably due to protruding elevations in the substratum. Superimposed upon them are smaller undulations which Nansen assigns to the driving of the snow by the wind. Between these undulations in summer lie pools of melted snow, which have their inflow and outflow through small rills. The ice surface is most broken up in the border zones, especially in the west, namely by crevasses; these may intersect it for 100–150 kilometers inland. They increase in number especially at the head of ice streams that discharge into the fiords and thereby produce a greater motion in the ice back of them. In this respect the great fiord systems exert a formative influence far inwards upon the inland ice. The crevasses cross each other in different directions. In addition to them the blue bands are conspicuous,

i. e. strips of clear ice that contrast with the more air-filled surrounding ice. Parallel furrows are associated with this structure.

Finally it is the watercourses, the hummocks resulting from melting, and the dust holes that impart its distinctive character to the ice surface at its borders. Watercourses develop in summer, erode deep canyon-like valleys in places, and often disappear after a short, rapid course into crevasses; but at any rate they create surface inequalities which are not again smoothed out until winter. Where the ice sends forth tongues into the rocky valleys, the edges of the tongues melt against the heat-radiating rock, and deep runways are formed, one precipitous wall of which consists of rock, the other of ice, and in which the melt-water flows off (for a similar case in Ellesmere Island, see Fig. 72). Similar melt-water gulleys surround the nunataks. Standing water appears extensively in the shallow depressions in the ice or beside rocky slopes and especially, locally, in the numberless cryoconite holes that dot the surface of the ice. These are formed by the melting into the ice of the dust that reaches the inland ice from the ice-free belt. They sink like test tubes perpendicularly into the surface, the holes being 5–10 centimeters wide and as much as half a meter deep; at the bottom lies fine mud and over it stands a column of water. These holes in places honeycomb the ice in the west.

The ice border itself in northern Greenland is for the most part steep and precipitous like a wall (Fig. 79); in central and southern Greenland it descends more gently, like the glaciers in lower latitudes. Where the edge touches the sea, whether in a broad front 30 to 50 meters high or in a narrow fiord compressed into an ice stream (see Fig. 78), it breaks off in pieces: the ice "calves," i. e. it forms icebergs. These owe their extremely varied shapes and heights to the compressure the ice undergoes in the fiords and to cleavage. Their greatest height, as measured by Drygalski, was 137 meters. On the central west coast they reach deeper water immediately and, as soon as the ice covering in the fiord is broken, drift away. In the great fiords of the east coast, on the contrary, they are held fast behind an outer submerged threshold until they melt away. In some places the inland ice discharges with so gradual a slope into the sea that no icebergs are formed; this is the case on long stretches of the northeast coast. Here the fiord ice merges so closely with the discharging glacier ice that the boundary between the two is scarcely noticeable when snow covers them. The whole movement of the ice border goes back to internal processes of motion, which in turn are based on the melting and refreezing of the ice, the temperature of whose deeper layers hovers about 0° C. With an outward horizontal motion, which in the border zone averages 1 meter an hour, is associated, according to Drygalski, a predominantly downward vertical motion in the central region and, on the extreme outer borders, an upward vertical motion.

The inland ice is fed mainly from the east. It suffers loss mainly in the west, through melting and the formation of icebergs. The east is the great region of origin, the west rather the terminal region of glaciation, comparable to the tongue of a giant glacier. In the east, therefore, the ice surface rises towards the nunataks, in the west it descends alongside them to form melt-water gullies. The mountains of the east are clothed with inland ice to their highest peaks, whereas in the west the whole border mountain zone is bare. This ice-free

FIG. 78—Tyndall Glacier, Whale Sound (at the mouth of Inglefield Gulf), Hayes Peninsula: an example of an outlet glacier by which the inland ice discharges directly into the sea. (From a woodcut based on a photograph by I. I. Hayes in his "The Open Polar Sea," New York, 1867, opp. p. 438.)

zone further favors the ablation process in the west, since it is from this zone that the dust reaches the ice border. Indeed the cryoconite holes form a uniform horizon in the west but are almost entirely lacking in the east. Finally, the summer temperature in the west is several degrees higher than in the same latitudes in the east. Ablation is estimated to amount to 2.3 meters a year at the western edge of the ice, and to 1 meter a year in round numbers for the whole belt, which is about 100 kilometers wide, in which dissipation takes place. The rather high annual range of temperate of the air above the ice disappears at a depth of a few meters, and farther down the temperature of the ice increases about 1° in 20 meters. The average air temperature in central Greenland was calculated by Koch and Wegener to be −32° C. as based on their measurements of the ice temperature.

The Marginal Regions of South Greenland

In the whole southern third of Greenland there are (with the exception of moraines) only two small places with post-Archean rocks;

together they comprise about 250 square kilometers. They are the red Igaliko sandstones (Cambrian-Ordovician) near Julianehaab overlain by volcanic sheets, which Giesecke had already interpreted as belonging to the same horizon as the Old Red Sandstones of Scotland, and the Arsuk group (Algonkian?) of the densely folded shales near Ivigtut. Otherwise South Greenland is a gneiss plateau, inclined towards the basaltic zone of the interior, with a large number of batholithic intrusions. On the west it may be considered to extend

FIG. 79—End wall of the inland ice 40 meters high at Ymer Nunatak on the eastern side of the ice cap in 77° 20′ N. (just west of the arrow along Mikkelsen's route on Fig. 74). This is not the outer margin of the ice cap but a wall facing inward toward that nunatak and lies about 50 kilometers from the outer margin. The fluting is due to melt-water running down the face of the wall; the dark horizontal bands are embedded moraine layers. (From J. P. Koch and A. Wegener, *Meddelelser om Grönland*, Vol. 46, No. 1, 1912, Fig. 39.)

to a point south of Disko Bay and on the east to very nearly the same latitude (68°). With Passarge and Nissen this region may be subdivided still further, especially according to the plant covering. But its structure and its girdle of skerries make it a major homogeneous unit. The rocks are principally gneiss and granite, also syenite and diabase. The above-mentioned small sandstone area is distinguished orographically in that it consists of plateaus with dark red slopes. Elsewhere in the southern district the landforms are mostly alpine. In jagged forms the mountains at the southern end rise to over 2000 meters, dissected by fiords and sounds and furrowed by innumerable glaciers that arise from separate ice caps.

On the east side up to Angmagssalik the coast belt practically maintains the same altitude and degree of dissection; but the inland ice leaves free only a narrow strip—in the extreme south it is scarcely 10 kilometers wide. On the west coast, on the other hand, there

begin from as far south as Julianehaab rounded forms with lesser heights, mostly under 1200 meters. Here, on this almost 1000-kilometer-long stretch, the same basement structure and the same rounded topographic forms prevail with few exceptions; at the same time the ice-free land grows in width as one goes northwards, in places to as much as 150 kilometers. In places also belts parallel to the coast are clearly discernible: a low outer platform in the form of skerries (Fig.

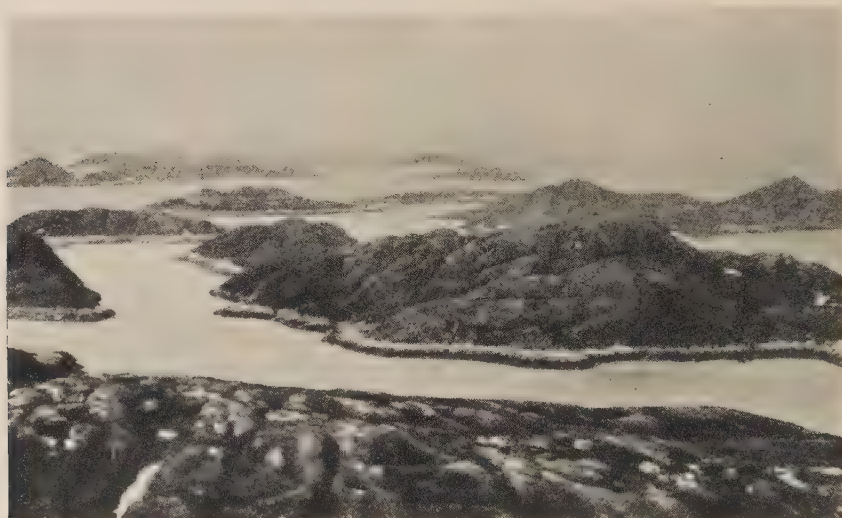


Fig. 80—The belt of skerries along the outer edge of the west coast of southern Greenland (north of Frederikshaab in 62° 30′). (From *Meddelelser om Grönland*, Vol. 61, 1921, Pl. 114, Fig. 1.)

80); then the higher alpine ranges; farther in, the interior peneplain which finally decreases in elevation and breaks up into hilly land.

The outer skerries are bare; farther inland along the fiords the mountains bear vegetation on the lower slopes; and in the innermost branches a luxuriant plant growth flourishes among high, snow-covered ranges, chiefly on granitic soil, least on the syenite. This growth constitutes the "forests" and bush formation (Fig. 81). Willows (*Salix glauca*) predominate; next come the birches (*Betula odorata, B. glandulosa*, north of 62° also *B. nana*). Alders (*Alnus ovata*), mountain ash (*Sorbus americana*), and dwarf juniper (*Juniperus communis*) also occur. On southern slopes in the southernmost section the birches develop stems as much as 20 centimeters in thickness and from 3 to 6 meters in height. Keeping pace with the northward decrease of the tree formation, there appear, as already stated in the general survey, bush, grass, and herbaceous formations, dwarf heather bushes, grass and moss moors, and rock vegetation of mosses and lichens with isolated shrubs and bushes. But even in the northern half of the west coast of South Greenland there are not much less

FIG. 81

FIG. 82

FIG. 81—Birch "forest" in southernmost Greenland (Kingua valley off Tasermiut Fiord, between Cape Farewell and Julianehaab). (From *Meddelelser om Grönland*, Vol. 61, 1921, Pl. 123, Fig. 8.)

FIG. 82—Site of Herjolfsnes, the present Ikigait (west of Cape Farewell), one of the old Norse settlements in Österbygd, the Eastern Colony. The ruins of the church are visible at the left, at the head of the bight in the foreground. Excavations were made here in 1921. (Photograph from Poul Nörlund.)

than 300 higher plants, as is the case at the extreme southern end, while in between there are fewer. The east coast exhibits the same types with the exception of the forests. Even around Angmagssalik bush formation occurs on the south-facing slopes, consisting principally of species of willow and juniper; willows here rarely reach a height of 1 meter, while their outspread branches reach a length of 3 meters. The annual precipitation of 950 millimeters is still very high, higher than in the same latitude on the west coast.

In an account of his visit, in the Julianehaab district, to a Dane born in Greenland, Giesecke says that he still had seven cows at pasture "in a very grassy fiord, the former abode of the old Norsemen," and, notwithstanding his eight or nine children, was able to sell fresh meat and cultivate garden produce such as cabbage, lettuce, spinach, radishes, and white turnip. Here Eric the Red found the "green land," as he could rightly name it, in contrast to the "wastes" and "Gunnbjörn skerries" which had previously been discovered. Here he sailed into its fiords and named them. After three years he returned to Iceland in order to colonize Greenland on a new voyage in about the year 984. Here arose the two colonies, Österbygd near Julianehaab and Vesterbygd near Godthaab. The southerly one lay directly in the Igaliko sandstone area; the northerly one in the warm, mild background of the deeply penetrating fiords. The ruins, the greatest of which are those of a "cathedral" 25 meters long, have for two hundred years been the object of extensive archeological research (Figs. 82, 83). From these investigations, supplemented by the material of the Icelandic sagas, it has been possible to reconstruct a vivid and comprehensive picture of this early Scandinavian colonization; this has been especially well done by Daniel Bruun.

FIG. 83—Woman's dress (left), about the year 1400, and man's dress (right), fourteenth century, from the excavations at Herjolfsnes in 1921. In cut and style the costumes were an imitation of the European fashions of the day or of a period slightly preceding it. There seems to have been no attempt at adaptation to the Arctic climate, nor is there any trace of Eskimo influence. (Photograph from Poul Nörlund.)

Today, also, this same southwest coastal section is the best suited to human habitation. On the east coast the inland ice leaves too little room. Here in the west, however, there is plenty of open coun-

Fig. 84—Holsteinsborg, a settlement and port on the outer coast of West Greenland where the marginal belt of ice-free land is widest. The new church is built on a flat-topped surface representing an uplifted strand platform. The large building in the foreground is a new cannery. (Photograph by L. M. Gould.)

try; and, furthermore, much pack ice from the East Greenland Current drifts along here towards the north and affords favorable conditions for seal hunting. The kayak is put to the greatest use. On the other hand, there are no sleds and no dogs south of latitude 67°. On land the fox is hunted in winter. Near Ivigtut is one of the few mining enterprises of the country, the unique cryolite mine. The locality is a Danish mining colony, not an Eskimo settlement.

The region of densest colonization lies between Cape Farewell and Cape Desolation. Its center is the Julianehaab settlement with 450 inhabitants. Additional larger places and important harbors of the west coast are Frederikshaab, Godthaab, Sukkertoppen, and Holsteinsborg (Fig. 84), each with 300 to 600 inhabitants. Garden cultivation, which produces today the vegetables mentioned by Giesecke in his time and even potatoes, is limited to the larger colonies and the Danish settlers. Between the colonies the coast is occupied by small Eskimo settlements, mostly at short distances apart. Only isolated stretches are entirely uninhabited, for example one 70 kilometers long north of

Holsteinsborg, where the skerry wreath ends. For the greater part of the coast the location of the settlements on outer small islands and projecting points is characteristic. The reason for this is evidently that the seal hunter can in such places easily carry his kayak to one side or the other according to the wind and put it in the water, and moreover he has a larger hunting ground before his door than if he lived in a fiord.

On the east coast of South Greenland Angmagssalik is the only settlement. It is situated south of the Arctic Circle. High mountains of alpine character form its background, ice and snow are its setting almost the whole year. The coastal belt, which here is somewhat broader, is broken up into many smaller and larger islands, high and rocky. Currents keep the passages open between them even when the solid ice pack lies outside. Thus there is opportunity for seal hunting. The lonely settlement has been known only since the eighties; and its inhabitants have, to a greater degree than those of the west coast, a distinctive culture of their own. Nevertheless, even they have already become partly Christianized, and the Danish trading station that has existed there since the nineties has hurriedly brought them a variety of acquisitions of European civilization. Since then the population has more than doubled and now amounts to 650 in round numbers. Once a year a ship takes away the output of polar bear and Arctic fox skins.

Central West Greenland

At latitude 69° the picture changes entirely on the west coast. Even the map's outline teaches this. In place of the narrow, astonishingly regular, only slightly branching transverse fiords, now appear broad, round bays, peninsulas, and islands, only in the rear of which do fiords penetrate still farther into the land and tap the inland ice. The most remarkable features are Disko Bay, Vaigat Strait, Umanak Fiord (Fig. 85), Disko Island, and the peninsulas Nugssuak and Svartenhuk. Of these the three land members consist principally of immense basalt flows resting partly on the basement rock, partly on Cretaceous and Tertiary sedimentaries. The whole series lies horizontal—the sedimentaries in a succession of sandstones and shales over 1000 meters thick with intercalated coal beds; the basalt cover, also over 1000 meters thick, interrupted by numerous intrusive dikes. The basement complex consists of gneisses and crystalline schists and likewise constitutes the surface rock over large areas—the basement rock more in the interior, the basalt in the outer part of the zone.

The topographic form of the region is on the whole that of an elevated peneplain rising to 2000 meters and more, tending in the basement-rock area to the same rounded forms as in South Greenland and in the basaltic area to more level forms that are bounded by terraced

cliffs deeply incised by many erosional valleys. Disko Island consists almost entirely of basalt and is for the most part 1000 meters high; Nugssuak in its basaltic part is almost 2000 meters high, in the basement-rock area lower. Svartenhuk is also less high. There is no inland ice on any of the three. The snow line in the marginal belt lies below 1000 meters; on the inland ice it rises to 1500 meters. Boulder trains, boulder beds, and extensive moraine ridges testify to the former greater extension of the ice. The numerous rocky basins of the gneiss surface are filled with lakes. They and the many moraine and ice-margin lakes make the coastal belt one of the most lake-studded regions of the earth. On the other hand, rivers and brooks here attain only slight development. The ice streams, however, are developed on a large scale, carrying, as they do, the inland ice into the sea and through their output being the palpable evidence of the drainage system of the land. The three largest are close together: the Jakobshavn, the Torssukatak, and the Great Karajak Glaciers, the last being 7 kilometers wide (Fig. 86). From them are calved most of the icebergs that leave the coast of Greenland. Even Humboldt Glacier on Smith Sound is secondary. These gigantic ice masses floating in the fiords, which on breaking off or overturning can set in motion the surface of the water for a distance of 50 kilometers; their breaking asunder with a roar like thunder; their fantastic shapes in the form of castles, crags, and bridges; the blinding radiance which they give forth in the bright sunlight as they lie crowded together out at sea or before the dark palisades of the basalt coast—all this is part of the picture of the central West Greenland coast in summer time. As to the mouth of the ice stream a winter and summer condition must be differentiated. In winter the icebergs that are formed have, on account of the barrier of fiord ice, no free outlet; instead they grow into massive dams formed from mountainous pieces and fragments as well as blocks of compressed floes piled up steep and wall-like between them. "While the development of the winter condition begins slowly and gradually increases, as the continual production of icebergs compresses the pack ice and pushes out the limit about which the ice edge oscillates, the break-up of the winter condition follows in separate catastrophes which are designated as ice-fiord discharge (*udskjyde*). . . . Through the discharge of the fiords there arises the host of icebergs that one meets everywhere in the waterways of Greenland in June and July and that are not scattered until they reach the open sea. The reason for the break-up of the winter condition lies, of course, in the loosening and disruption of the fiord ice which the jam has held together. . . . When the loosening has taken place, it is the force of the föhn winds plunging down from the inland ice with elemental power that set in motion the pack-ice" (von Drygalski). Therefore, as the investigations of the present writer have shown,

the wind and air-pressure situation of a given summer in the region of these fiords determines the following spring's quantity of drifting icebergs even so far south as Newfoundland.

Disko Island has noticeably warm summers, to which the extent of its ice-free surface as well as the intensely heated basalt rocks may contribute. On protected and south-facing valley slopes the "forest" of willows and dwarf birches here still reaches such a size that a man

FIG. 85—Umanak Fiord, looking northeast from the north shore of Nugssuak Peninsula. (Photograph by Arnold Heim in *Meddelelser om Grönland*, Vol. 47, No. 3, 1911, Pl. 19.)

may almost disappear in it. There are over 200 species of higher plants. The Eskimos, too, are aware of the favorable conditions. They have a legend that a boatman conveyed the island up from the south.

By the middle of June vegetation is fully developed in the whole central coastal section. The gneiss rocks are covered with black, red, and green lichens. In the midst of the grasses and mosses all sorts of flowers shine forth, rhododendron, saxifrages, poppies, and numerous others. Willows with their catkins creep up the soft slopes of the rounded elevations, and the water pools in their hollows are surrounded by bulrushes and cotton grass. "In the second half of June we find all hollows and slopes that permit the establishment of plants between the bare rocks richly decorated with blossoms. A thick greensward formed of crowberry and willows, whortleberries and birches is adorned with the white bells of *Cassiope tetragona* and the upright flower clusters of the wintergreen, *Pyrola grandiflora*. Between blue spikes of *Luzula* and sedge there rise like gorgeous bouquets bushes of rhododendron and white marsh rosemary, whose thick

blossoms conceal their leaves. Near them the heads of the yellow poppy wave in the wind. Nestling on the ground in sunny places there shine forth the blossoms of the *Dryas* like small white roses, the thick starry flowers of the red saxifrage, and the stemless pink. On dry land white Silenaceae and a number of species of saxifrage stand out, while wet ground is characterized by the white calyx of the *Diapensia*, the flaming red or white inflorescence of the lousewort, and rose-red

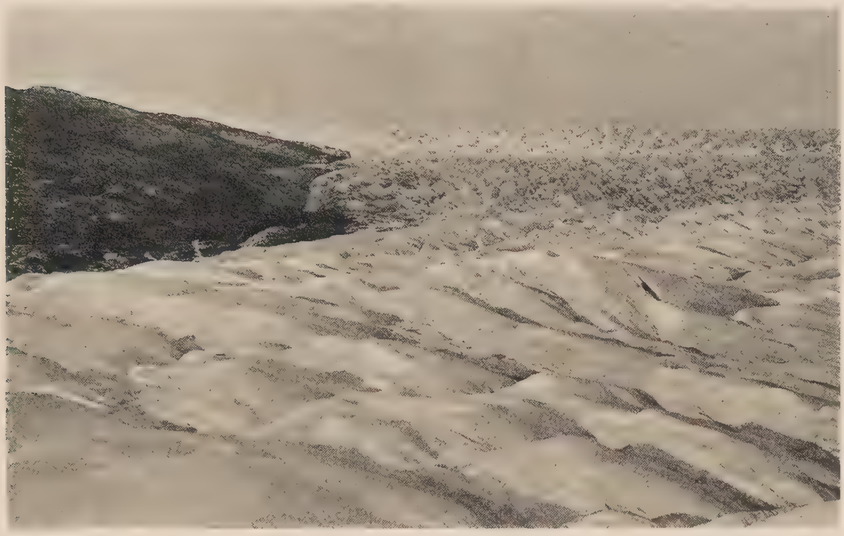


FIG. 86--The Great Karajak Glacier, a glacier draining from the inland ice directly into the sea (at the uppermost end of Umanak Fiord). From this glacier and two others debouching into Disko Bay are calved most of the icebergs that ultimately enter the Labrador Current. The view is looking upstream, with the shoulder of Karajak Nunatak on the left. (Photograph by Arnold Heim in *Neujahrsblatt der Naturforsch. Gesell. in Zürich*, No. 113, 1911.)

blossoms over four centimeters wide of the willow-herb." This colorful summer picture is due to Vanhöffen.

The settlements in the outer basalt region have a somewhat different situation from those on the gneiss coast farther back. On Nugssuak Peninsula and Disko Island they generally lie on straight stretches of the coast, Godhavn, for example, on the south coast of Disko Island, while Svartenhuk is entirely uninhabited. The combined basalt and gneiss coast namely has a simpler outline than the pure gneiss coast. Where the latter occurs, as on the rear side of Disko Bay, the settlements prefer the same promontory situation as in South Greenland, e. g. Jakobshavn. In the outer basalt zone, on the other hand, there is a smaller choice of headlands; but there is such an abundance of seals in outer Disko Bay, Vaigat Strait, and Umanak Fiord that to establish settlements here commends itself for that reason. The chief place is Jakobshavn with over 400 inhabitants. Claushavn and Christianshaab are smaller. The latter because of

its excellent harbor is a prominent trading center. All three lie at the back of Disko Bay, the entrance to which is flanked to the north by Godhavn on Disko Island and to the south by Egedesminde. On Umanak Fiord is situated the community of that name. All are places with a few hundred inhabitants.

The Upernivik District and Melville Bay

From a point north of Svartenhuk to Cape York the sedimentary and basalt zone is again lacking. The uniform basement complex of gneiss, crystalline schists, and some granite again occupies the whole belt to the outer coast. And yet the landscape has a different character from that of the South Greenland gneiss zone and may also be divided into two different sections—the Upernivik district in the south and Melville Bay in the north (see Fig. 87).

The Upernivik district is no longer a fiord region; it is a labyrinth of skerries. The whole strip of land, here narrowed down, is broken up into a host of islands mostly of moderate height and of rounded shape. In the immediate vicinity of Svartenhuk the islands and peninsulas are still fairly large patches, but then, as the zone grows narrower, they become a multitude of specks. Some of the sounds between have a depth of 1000 meters, others are barely covered with water. The ice is broken up earlier in the season on account of the freer access of the sea, and sledge travel is restricted. Large numbers of icebergs from the great fiords often drift still farther north before they turn into the westerly southward-flowing currents. As to vegetation the rock plant association predominates. The number of species is much less than at Disko and Svartenhuk. Nevertheless the west coast even to this latitude is relatively favored, especially in summer (July average, 5.0° C.), as warmer water reaches thus far with the West Greenland Current. Even in latitude 72° 48′ there is a colony and trading post, Upernivik, with over 200 inhabitants. In addition there are about a dozen smaller settlements, some to the south, most of them immediately north of the colony. They lie mainly on the outer border of the belt of skerries. The most northerly is Itivdliharsuk in latitude 73° 30′.

Melville Bay is almost entirely surrounded by the edge of the inland ice except for isolated spurs and very small islands. A prominent, precipitous formation of this kind, which lies at the southerly end of the bay, has been named "Devil's Thumb." At its northern end a number of large nunataks rise out of the inland ice, the most prominent of which is Mt. Haffner. The crossing of ice-jammed Melville Bay is often very precarious for vessels bound for Smith Sound, and whalers are fortunate if they are not delayed here more than three weeks. But beyond, open water usually lies at the entrance of

Smith Sound, the so-called "North Water," in regard to which the author established the hypothesis that it arises through the ascent of the warmer deeper waters of Baffin Bay coming from the south.

Hayes Peninsula

At Smith Sound, forming one side of this strait, there lies the broad northwest buttress of Greenland, Hayes Peninsula, between latitudes 76° and 79° (Fig. 87). It is the smallest area deserving to be established as a separate region within the scope of our discussion, but it is of marked individuality and clearly circumscribed. North as well as south of it the inland ice reaches the sea, south in Melville Bay, north in Humboldt Glacier. The latter is the broken-off front of the inland ice extending over 100 kilometers almost in a straight line back of Kane Basin; in form it is smooth and even, without fissures and with comparatively little motion and life; yet it is a nursery for icebergs, which drift south through Smith Sound. The inland ice also advances in two great lobes into Hayes Peninsula, which itself is separated into two peninsulas by Inglefield Gulf. The northerly one is named Prudhoe Land; the southerly, nameless, is in turn subdivided into two projections by the smaller Wolstenholme Sound. Both gulfs are wide at their entrances but become narrow and pointed at their heads. The whole ground plan has a predominantly west-east direction, as does also the southern boundary of Hayes Peninsula at Melville Bay; while the northern boundary at Kane Basin runs at a slight angle to this direction and thereby creates other small bays striking in obliquely.

Hayes Peninsula is a plateau 700 meters high. Its foundation, like that of all West Greenland, is gneiss, but here the gneiss surface gradually dips toward the north. At Melville Bay still this rock lies directly under the inland ice. On the north coast of the peninsula the gneiss, to be sure, again protrudes from under the ice; but, from Wolstenholme Sound almost to Humboldt Glacier, it is mainly superposed Cambrian and Ordovician strata that appear on the coast. These are horizontal beds of sandstone in part with diabase intrusions. They extend northeastward under the inland ice, evidently as a broad belt, and have again been met with south of Peary Land, as also farther west in Ellesmere Island.

Climatic conditions are greatly inferior in winter as compared with Upernivik; the mean temperature of the coldest month is at least 10° C. lower. The warmest month, however, is only about 1° cooler than in Upernivik. From the Greenland side a relatively warm northerly current is reported in this latitude, from the Grinnell Land side a cold southerly current.

Vegetation also is more abundant on the Greenland side. From Foulke Fiord at Etah alone about 75 phanerogams are known. A

thick grassy carpet, and not primarily bare rock, characterizes the landscape. There are *Arnica alpina*, *Ranunculus*, *Dryas*, *Potentilla*, *Salix arctica*. Mosses play an important part; they surround small mountain lakes in thick, soft beds. Also on Wolstenholme Sound,

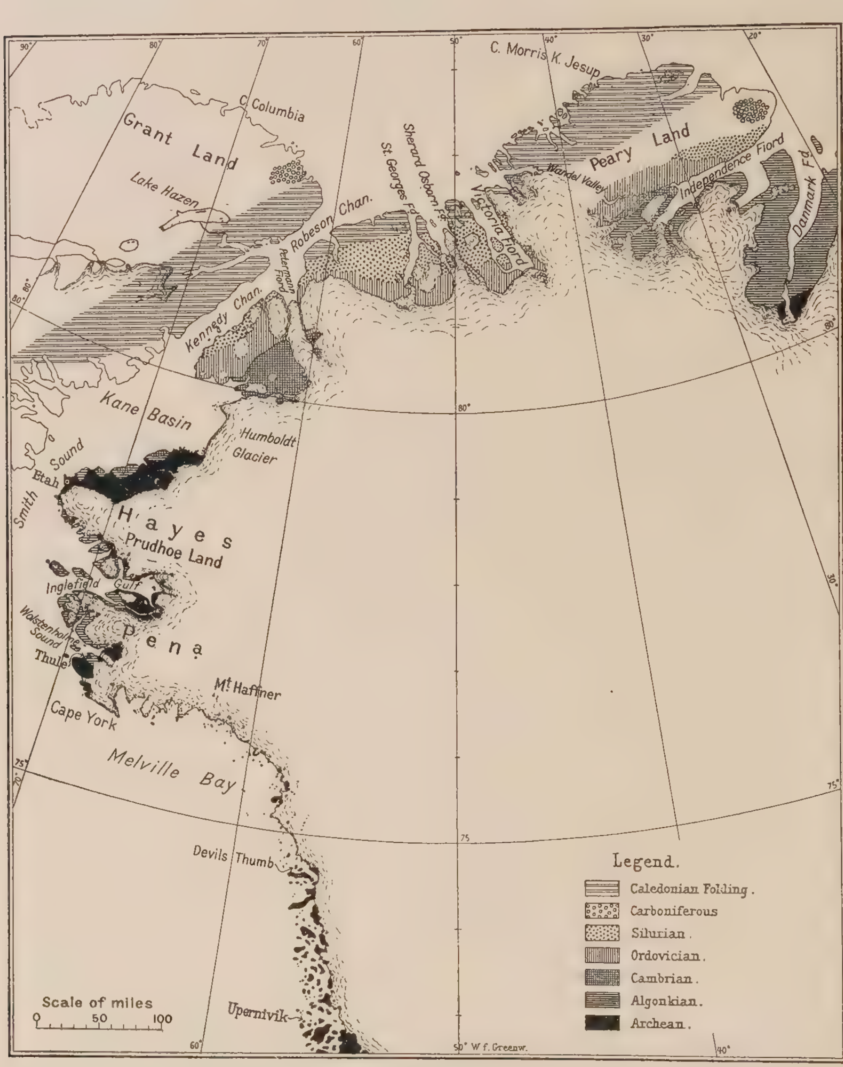


FIG. 87—Geological map of North Greenland by Lauge Koch. Scale, 1:9,700,000 approx. (From *Geogr. Tidskrift*, Vol. 27, 1924, p. 212, with names added.)

Inglefield Gulf, and other places on the westward-facing coasts Arctic oases are known. As a result of the intensive east-west embaying, there are many slopes inclined to the south and southwest, broad-mouthed valleys, and large areas of ice-free land that afford room for plant and animal life.

The animals, especially immense flocks of dovekies, gulls, guillemots, and petrels, fertilize the soil and thereby promote vegetation. From the flowers insects suck their nourishment—bumblebees, butterflies, and mosquitoes—they in turn becoming the prey of birds. The reindeer, too, find their pasturage here when they come out of the hilly interior in summer. Foxes are abundantly represented, especially the blue fox. Furthermore, polar bears, wolves, hares, and musk oxen occur; in winter they all cross Smith Sound, which is frozen over at its narrowest spot. Musk oxen appear in herds of as many as 200, although great numbers of them have been hunted down by Eskimos as well as polar travelers. No less abundant and still more important as food for man is the life of the sea. Walrus and seal are both found here the year round, the walrus in Smith Sound itself in great herds.

This small oasis of land in the high Arctic is the habitation of the northernmost tribe in the world. They were discovered in 1818 by John Ross and were called "Arctic Highlanders." Since Bessels' time they have been called Etah Eskimos from their dwelling place. Lately they have become the object of thorough research, especially by the Danes, and have been designated Polar Eskimos, or "neighbors of the north pole." Isolated by the inland ice and the sea, without connection with the West Greenlanders or the Eskimos of Baffin Island, they formerly believed themselves to be the only people. They were so poor in wood and iron (meteor iron) that some of their weapons and boats were made of pieces of these materials bound together and their dog sleds were made of bones. They had no bows and arrows; they were unacquainted with reindeer hunting and salmon fishing; and they did not know, or had forgotten, how to build kayaks. Not till the sixties did they acquire these attainments through an Eskimo band from Ponds Inlet. In 1904 Danish explorers showed them the route across Melville Bay to the nearest trading post, with which they have since come into yearly contact. Now the Thule trading station exists in the region. They obtained many modern articles, especially weapons, from Peary, who spent some time with them. In 1895 he found there 253 persons, in 1906 only 207; in 1922 some more of them were carried off by influenza. In summer they live in tents; in winter in low, elongated flat-domed houses, which are now chiefly built of stone supplemented by skins and earth. In earlier times they were made also of whale bones. On their winter journeys they build snow huts. Their permanent houses lie upon the lower shore of the large bays. Only in these bays do they find good level ice for about three-fourths of the year such as they need for their sleds, as they are almost entirely adjusted to the hunting of sea animals from the ice. Headland sites like those of the colonies in West Greenland are for them of no importance, as the kayak, although they use it now, is not necessary; dog sleds and ice hunting

are the fundamentals. In this way they hunt the seal, white whale, narwhal, and walrus.

Their land hunting is concerned with the musk ox and the polar bear, lately also the reindeer. They hunt the musk ox in Ellesmere Island, the polar bear on their own side of Smith Sound, to the north and south. No other Eskimo tribe makes such free use of bearskin for clothing. The bear is therefore as indispensable to them as is the reindeer for others. Polar bears are numerous in Kane Basin and along Humboldt Glacier, as well as in Melville Bay. So their hunting grounds and their economic area extend as far to the north and south as to the west. It has a radius of about 300 to 400 kilometers and includes three quadrants. In the fourth quadrant only are they limited by the inland ice. Most of the hunting occurs in the autumn and spring as well as at the beginning and end of winter. In summer they hunt dovekies in large numbers for an easy winter supply. Warm soft underclothing is also fashioned from the skins of these small birds—a peculiarity of the tribe. The booty of the hunt, because of the difficulty of transportation, is laid down in depots far from the settlements, where it remains frozen until needed.

The habitations are scattered over hundreds of kilometers from Cape York to Etah and, in their own terminology, are divided according to the winds: the neighbors of the north wind, of the southwest wind, those between the winds, and in the lee of the southwest wind. The dwellers in the lee of the southwest wind, near Cape York and to the south, have the most abundant bear hunting. The dwellers around Inglefield Gulf (lee side) can store up great quantities of food for winter from the available great meat-furnishing animals, walrus, narwhal, and white whale, and from their fat they can procure more light and warmth than from seal fat. They therefore have the largest and warmest houses as well as numerous well-nourished dogs; but they have no bearskins, which they need for renewing their trousers and bed covers. Thus there is still variety in the conditions of existence of the Arctic Highlanders. But this variety exerts no permanent influence upon them: their wanderings prevent that. These wanderings really consist merely in an exchange of stone houses and hunting grounds; a dweller in the southwest wind will settle down every few years to a more comfortable life in the opulence of the lee-side men, and vice versa.

Of all Greenland tribes these Eskimos have been the least in contact with civilization. Their hunting instincts are undiminished; the search for danger, the penetration into the unknown are in their blood; and so they have proved excellent helpers, courageous and self-sacrificing companions on expeditions, formerly with Kane, Hayes, Hall, and Nares, recently under Peary's and Rasmussen's experienced guidance.

North Greenland

In the earlier and recent history of discovery North Greenland up to and including Peary Land has been closely associated with Hayes Peninsula, partly because Smith Sound was the frequented route to the pole from the seventies on—as a result of which the coastal outline of North Greenland was disclosed on sledge expeditions—and partly because the land of the Polar Eskimos was used as a base for crossing the northern end of the inland ice, past Humboldt Glacier towards Peary Land. From the standpoint of physical geography as well as biogeography North Greenland should be considered a separate region. In the west it is clearly separated from Hayes Peninsula by Humboldt Glacier; in the east Danmark Fiord may be taken as the boundary against Northeast Greenland. Thus it lies entirely to the north of latitude 80°. Its survey has only just been completed by the recent three-year journey of Lauge Koch (1921–1923), while to Peary belongs the merit of having established its northern limit (1900).

The northernmost end consists of Peary Land, which Peary himself believed was separated from the rest of Greenland by a channel forming the northwestern continuation of Independence Bay, which enters from the east (Fig. 88). The non-existence of Peary Channel was then recognized by Mylius-Erichsen and Rasmussen, until finally Koch brought back the explanation that, to be sure, no continuous water passage existed, but that there was a deep depression, which he calls "Wandel Valley." It is somewhat of an analogue to the Caledonian Valley (Glen More) of northern Scotland. In the divide region there lies a long, narrow lake at an elevation above sea level of 200 meters, indicating that in all probability the through water connection still existed after the Glacial Period. Between Kane Basin and Wandel Valley several long fiords penetrate inland, the most important being Petermann Fiord, St. George's Fiord, Sherard Osborn Fiord, and Victoria Fiord. The rectangle of land between Petermann Fiord and the next adjoining fiord to the east, Newman Bay, is named Hall Land, upon which lies Thank God Harbor, well known as the wintering station of the *Polaris* expedition (1871–1872). Between Newman Bay and St. George's Fiord lies Nyeboe Land. The projection in the east between Independence Fiord and Danmark Fiord is called Mylius-Erichsen Land. Petermann Fiord penetrates far into the inland ice, Sherard Osborn Fiord somewhat less, as the ice-free land becomes wider and wider towards the northeast, until finally Peary Land is no longer reached by inland ice at all and exhibits only slight local glaciation. This glaciation does not appear to have been substantially more extended during the Pleistocene.

From Lauge Koch we have for the first time obtained a complete geological picture of North Greenland (Fig. 87). North of Humboldt

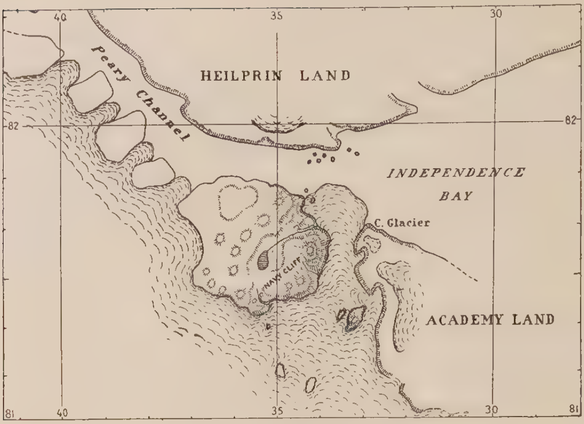


Fig. 1 Peary's Map, 1892

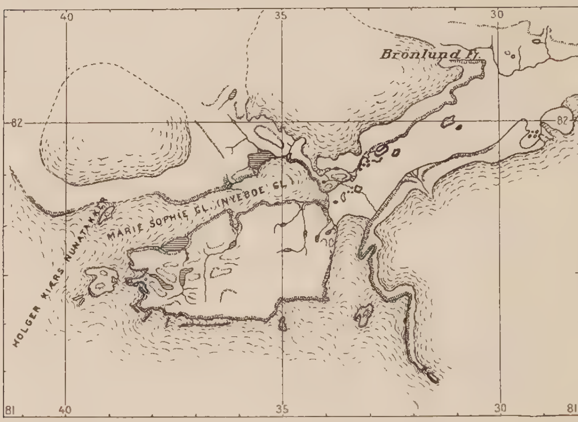


Fig. 2 Rasmussen and Freuchen's Map, 1912

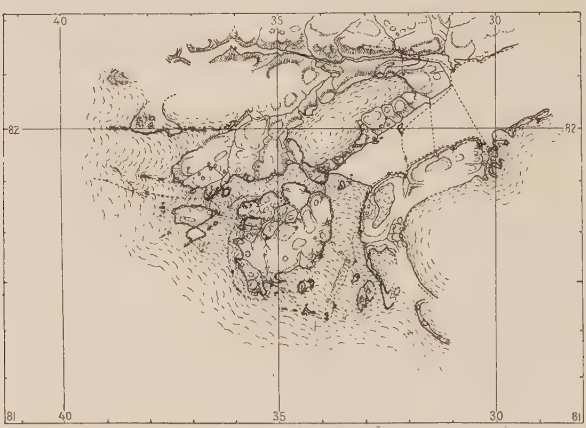


Fig. 3 Lauge Koch's Map, 1921

FIG. 88—Progressive representation of Peary Channel region. Scale, 1:2,800,000.

Glacier appear high plateaus of Middle and Upper Silurian limestones, as is also the case west of Smith Sound. They are slightly inclined to the northwest, otherwise almost undisturbed. Extended plains and broad valleys are here characteristic of the landscape. Then follows a strip of Devonian sandstone, unfolded and soft enough to form a zone of depression which can be followed from Hall Basin northeastwards to Nordenskiöld Fiord. Then only there follows a folded mountain belt, probably folded in the Devonian. Trending west-southwest to east-northeast it unites Grinnell Land and Grant Land with North Greenland and, up to the northeastern point of Peary Land, extends in round numbers over 1000 kilometers. This folded belt consists chiefly of sandstones. It is often alpine in character, with peaks more than 1000

meters high—on Peary Land even 2000 meters high. Numerous fiords cut across it. Faults seemingly are of no importance, whereas west of the Smith Sound axis they are numerous. In Peary Land the double zone is well marked: in the south the plateau 800–900 meters high, in the north the range with the greater heights referred to—the Roosevelt Range.

The ice-free belt of land, which here is broad, in summer becomes very moist; and rivers and lakes develop when much snow melts. The average July temperature is little over 2° C. Of the 108 flowering plants in the whole of northwest Greenland more than half still appear north of Humboldt Glacier. Among them is *Pleuropogon sabinii*. Even on Peary Land the desolation one might expect in the northern end of Greenland does not prevail. "Thick, well-developed grass grew in many places," "everywhere sturdy Arctic willow, poppy, saxifrage, and *Cassiope*" (Rasmussen). And upon these "stunted children of the sun," which are conjured forth in a single month, is built up a relatively abundant life of musk oxen, lemming, and hares; and upon them in turn that of the wolf and other animals. Polar bears, seals, whales, snow buntings, snowy owls, gulls, and snow geese are also plentiful.

The characteristic animal of the whole of North Greenland, however, is the musk ox (*Ovibos moschatus*, see Fig. 17, p. 66 above). The First Thule Expedition maintained itself on 84 of these animals. For permanent human habitation, however, there does not seem to be a sufficient basis, since Rasmussen, who lived Eskimo fashion, nevertheless had difficulty in providing himself and his few companions and dogs uninterruptedly with game. That men have never lived here for any considerable length of time is proved also by the absence of ruins of winter houses. Only tent rings were found, which point to a short summer advance or passage. On the east coast, the nearest winter houses are situated in latitude 80½° and, to the west, in Grant Land on Hazen Lake.

Northeast Greenland

The next individual region begins at the selected boundary of Danmark Fiord and from the prominent projection of Prince Christian Land extends with an outwardly rather uniform character to a point south of 74°, where the immense fiord system introduces a new type of coastal development. In structure, however, a change enters in somewhat farther to the north, between latitudes 75° and 76°. The exploration of almost the whole section is the work of a series of Danish expeditions which began with Mylius-Erichsen and were continued in order to ascertain his fate. The northern part, from Northeast Foreland, the extreme point of Prince Christian Land, to

77°, bears the name of King Frederick VIII Land; the part that follows to the south, King William Land; and on the coast lies Germania Land.

The essential features of the whole region are derived from the basement rock complex and the inland ice that rests upon it almost to the coast. The Archean rocks are sometimes replaced by patches of sedimentaries that lie over them or are embedded in them where fractured; they belong to the Carboniferous, Jurassic, Cretaceous, and Tertiary periods. In the general aspect of the coast, long stretches of outpouring inland ice alternate with broad ice-free areas and large nunataks in the background. Steep-walled valleys and fiords penetrate inland. The plateau form predominates, because of the horizontal position not only of the sedimentaries but also of the typical gneisses; and the elevations for the most part do not exceed 1000 meters. But a mighty nunatak stands out by reason of its height and form—Queen Louise Land, between latitudes 76° and 77½°. It towers 2000 meters in height, and its alpine forms are hardly matched elsewhere in the marginal belt: the highest peaks tower over the surrounding inland ice by about 1000 meters.

The farther north, the lower becomes the elevation at which alpine landforms still appear, a proof that in the far north the Pleistocene glaciation was scarcely greater than the present. In latitude 77°, on the other hand, the now free coastal land lay for the most part under ice, for the plateaus are undulating and rounded, the rocks scoured and polished. The thrust side of elevations is generally the steeper. Only little morainic material has been left behind. Detritus frequently shows a tendency to slide and to collect in hollows. On the coastal rocks of Germania Land strand notches and terraces testify to a postglacial uplift of 400 meters. On the shore of a lake lying 10 meters above sea level whale remains were found and at its bottom saline ground water.

The inland ice here again approaches the coast more closely than in North Greenland. Conditions resemble more nearly those of Melville Bay in spite of the scanty annual precipitation of 145 millimeters. At latitude 81½° the snow line lies at sea level; this is the only place of the kind known in the northern hemisphere. Floating inland ice and piedmont glaciation are also found here. In some places the ice edge is so flat that, coming up from the bay ice, one meets it unexpectedly; and again in other places it ends as a very steep, high wall (Fig. 79). The ice front at Borg Fiord, where Koch and Wegener ascended the inland ice, is described by them in vivid terms. "Like a mighty wall of marble 40 meters high the perpendicular cliff of the glacier rises from the fiord. The sharp edges, prominent corners, and carved niches, the many small angles and bays, capes, and tongues, that alternate with long straight lines, looked as if they were fashioned according to

the grotesque ideas and fancies of a humorous architect. Now one sees, as in a new marble quarry, a half-finished roughly hewn wall; now there meets the eye a smooth, bright surface which shines with the luster of a high polish; then again one perceives the humor of the master in baroque snow garlands, whose icicle fringe and tassels sparkle in the sunlight. Now the wall is a uniform white, like purest alabaster; now it is colored a pale brownish yellow or bluish gray; now the delicate colors occur in the form of broad bands like streaks in agate.

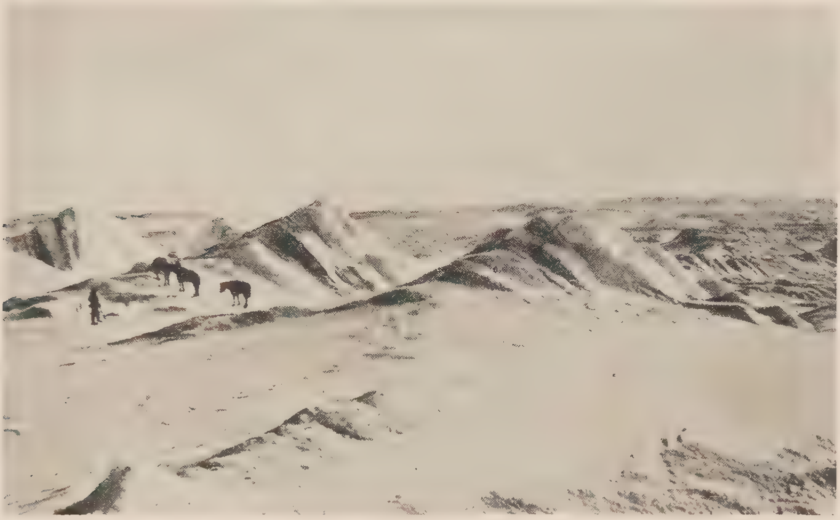


FIG. 89—Folds in the Storströmmen (Great Stream) debouching from the ice cap southwards into Dove Bay (west of Danmark Harbor in Fig. 74), northeast Greenland. (From J. P. Koch's "Gennem den hvide ørken," Gyldendal, Copenhagen, 2nd edit., 1914, opp. p. 216.)

It takes hold of one, it is disconcerting, this mighty wall whose foundation is sunk 200 meters deep in the loamy fiord water. It appears so unshakably firm, so eternal and unchangeable, that the mind can scarcely grasp the fact that it is the source of all the icebergs that cover the fiord, that from its front at the bottom of the sea the ice blocks detach themselves and are hurled to the top with such buoyancy as to shatter the ice cover of the fiord and make it surge up and down far and wide. A cobweb-like network of fissures still testifies to this surging motion kilometers away." Against the nunatak of Queen Louise Land also the inland ice ends in part in a vertical wall about 25 meters high. On the ice-free land the snow may collect in perennial drifts, or "snowdrift glaciers," which assume certain structural forms similar to those of the inland ice but have not mass enough for motion. In them, ice caves are easily formed by the effect of melting and evaporation and by the circulation of air and water.

The climate is most continental in the north and at the inland ice; it moderates southward and seaward. The average annual tem-

perature range in Danmarks Havn (latitude 76° 46′) was 32° C.; upon the somewhat more southerly Sabine Island, 28°. The extreme temperatures observed on the *Danmark* expedition were −50° and +17°. Summer can therefore bring great warmth. The July average is 4.4°, the February −27.4°. The wind blows most frequently and most violently from the northwest; at the height of about 1000 meters and above it blows almost constantly. It is dry and relatively warm, at times föhnlike, and associated with a characteristic stationary bank of clouds (föhn cloud). East winds are more frequent in summer but do not extend above 300 meters in height and reach only to the inland ice. They are moist and often bring fog. In 1900 this fog forced Peary to turn back on Peary Land, and it hampered the *Danmark* expedition on their sledge journeys. As it clings to the outer coast, it here retards the summer as compared with the inland ice edge.

The transition to summer is very sudden. At the time of the *Danmark* expedition the snow melted away in one day; the birds all arrived almost the same day, most of them at the same hour. Life appeared soonest on the east side of Queen Louise Land, which lies inland 30–50 kilometers distant from the nearest fiords. The members of the expedition were astonished "at the wealth of life which was found on these ice-encircled rocks, which *a priori* must seem condemned to absolute desolation" (J. P. Koch). Plants appearing in masses near Danmarks Havn were crowfoot, saxifrage, and whitlow grass. The dry gravel areas bear sparse vegetation, in which *Salix polaris* and *Saxifraga oppositifolia* predominate. Moist places support more continuous carpets of moss and grasses. Nearly 100 species of higher plants were collected north of latitude 76°.

The animal world in the coastal waters is primarily characterized by the high-Arctic walrus, the fiord seal, and the Greenland seal. The polar bear is so abundant that on the *Danmark* expedition alone 90 were killed. There are quantities of lemming, hares, and foxes; also of the newer interloper, the wolf. The musk ox is less frequent, the reindeer entirely gone. But the Eskimos whose ruins are found here must have hunted the latter. Perhaps it has only given way before the advance of the wolf. Bird life, again, is abundant. The insect fauna is of the same character as in the south, only poorer in species: bees, spiders, mites, and butterflies—the last in nine species.

Traces of old Eskimo settlements are plentiful between latitudes 74° and 78°. Fewer were found from 80° to Peary Land. They are frequently the tent rings of the summer dwellings. In places appear the ruins of winter houses and in addition simple stone huts, fox snares, meat depots, and the like. From the state of preservation of the stone houses Thostrup has deduced three periods of colonization, with intervals of several hundred years between the first two, while the latest may not go back more than fifty years.

Central East Greenland

South of Northeast Greenland the geological conditions are reversed to the extent that the basement complex becomes secondary and the sedimentary rocks come to the fore. At the same time the orographic aspect changes fundamentally because of the greater width of the ice-free lands (up to 200 kilometers) and of the unusually deep penetration of great fiord systems towards the inland ice. Thus the establishment of a central section of the east coast is justified. As the region of the great fiords it reaches only from latitude 74° to 70°. It is, however, appropriate to extend it a short distance farther north as well as farther south, in order to include the basalts, which are peculiar to the coastal strip.

Thus central East Greenland extends from latitude 68° almost to 76° and may be subdivided into three regions: (1) the middle stretch, characterized by gigantic fiords and the predominance of sedimentary formations in addition to the Archean rocks and the basalts; (2) the northern stretch, in which, aside from the basement rock, the Tertiary sedimentaries and basalts are almost the only ones that occur; (3) the southern segment, in which only an unbroken band of basalt accompanies the inland ice. The last-named forms the most extended basalt region of Greenland. It flanks Scoresby Sound and from there runs southward as a narrow coastal strip. A hot spring containing hydrogen sulphide was found here. Short fiords cut into the rectilinear coast line. The walls fall off almost perpendicularly, the basalt sheets forming terraces in them which the snow accentuates; the heights are plateau-like in character. In contrast to this great uniformity south of Scoresby Sound, the structure and formation and likewise the coloring of the landscape in the central part are extremely varied. Nowhere else in Greenland does such variety appear along the fiords: all types of landscape are present, and next to pronounced lowlands there are found the greatest absolute heights of the whole land. In general there may be distinguished north-south contiguous belts composed respectively of basement rock, older sedimentaries, younger sedimentaries, and finally Tertiary basalts. They follow one another in this order from the interior of the fiords outward, but only in a very general way. In the separate stretches of the coast many divergent features are introduced into this scheme by dislocations, accompanied by folding. They also for the most part have a north-south direction. This direction is thus indeed seen to predominate in the structure of the area, a circumstance that is also reflected in the outlines, e. g. in Liverpool Coast. In addition there is the transverse direction of the fiords. They are, from north to south, Franz Josef Fiord, King Oscar Fiord (Fig. 90), and Scoresby Sound—the most imposing fiord system of the earth. The first two penetrate inland close to each other; their branches coalesce in places, excising large islands. The third system

penetrates more deeply still and in ground plan is comparable to an immense delta with its head at the narrow entrance to the Sound and with the sides of its triangle measuring 200-300 kilometers in a straight line.

Otto Nordenskjöld thus portrays the great fiord region: "The scenery there is the most magnificent of its kind that I know of. The rock walls plunge abruptly down to the narrow blue fiord, on whose

Fig. 90—Part of the southwestern wall, 1360-1570 meters high, of King Oscar Fiord in the region of gigantic fiords on the central east coast of Greenland: Syltopparne ("Needle Points"), almost vertical Silurian strata. (Photograph by F. Åkerblom in paper by A. G. Nathorst, *Ymer*, Vol. 20, 1900, Pl. 9.)

surface float icebergs which, compared to works of man, our ship for example, are immense but appear quite insignificant when compared with this gigantic nature. Here the mountains are plateau-like in character, there they rise, especially where the strata are steeply inclined, to wild-looking peaks and ridges. Yet what makes the picture especially noteworthy is the glorious coloring, lacking elsewhere in the Arctic world, where white and blue in varying shades do indeed produce the most wonderful light effects but nevertheless prevail to the extent of monotony. Here the basement rock proper consists of highly colored, dark, violet, green, yellow, white, and especially glaring red strata. No vegetation cover conceals the aspect of the mountain slopes, which are crowned by a shining blue-white band of ice—a mighty mass which looks so thin only in consequence of its great height. Only in certain desert lands can the bare skeleton of the earth be seen in such colors as here. There, however, one misses the life and the contrast which sea and ice lend to this picture of the Greenland fiords." In the basement rock the plateau form predomi-

nates; in the sedimentary regions likewise, when the stratification is horizontal, but when the layers are steeply inclined the relief is very rough. Heights from 1500 to 2000 meters are numerous; in Petermann Peak at the head Franz Josef Fiord a height of 2800 meters is attained. Extensive Quaternary formations also are intercalated. This is the case north of Scoresby Sound, where there is a large continuous gravel plain, low, level, ice-free, and without trace of earlier glaciation.

As iceberg producers the gigantic fiords of central East Greenland are inferior to the somewhat smaller ones of the west coast. That is generally true of the ice streams of the whole eastern side; because of shoals off the fiord mouths the icebergs either do not become free at all or they do not drift far after their release before they run aground again or are carried into new bay ice. Thus for the most part they must waste away where they are, which, however, may take years. All the more characteristic of the outer coast is the barricade of pack ice. According to its density three belts of ice may be differentiated. Outside, off the continental slope, lies the loose and smooth ice that is locally formed in the North European Sea; over the coastal shelf zone the East Greenland Current trails along the more compact pack ice of the central polar basin; then follows the coastal fast-ice, which in summer, however, melts or disintegrates into the coastal waters. To approach the coast in a vessel, therefore, always involves breaking through the pack-ice belt over the coastal shelf. The higher the latitude the more difficult this becomes because of greater proximity to the original source of the pack-ice masses and because of the increasing width towards the north both of the coastal shelf and the current. It is precisely the coastal stretch of central East Greenland whose ice has most frequently called a halt to advancing expeditions. For this reason, also, of all the coastal stretches of Greenland it is the one that has drawn to it more persons of different nationalities than any other. In the last decades sealing craft have also penetrated into the pack-ice belt. From 1889 to 1920 eighty-one Norwegian sealing vessels were active in this region.

Near each end, northern and southern, of this stretch of coast an expedition has wintered—Koldewey on Sabine Island in 1869–1870 and Ryder on Scoresby Sound in 1891–1892. The temperature conditions of these two stations were found to vary but little. That the southern station was not warmer may have been due partly to the fact that the observations were made in different years or to the fact that it was situated in the interior of the fiord and consequently had a relatively more continental climate, that is, chiefly, a severer winter. The July temperature average is only about 4° C., as in Danmarks Havn; the coldest month, with a mean of –24° to –25°, is only slightly warmer than at that place, an evidence of the uniformity of the con-

FIG. 91

FIG. 92

FIGS. 91 and 92—The new settlement on Scoresby Sound, central east coast of Greenland. Figure 92 shows Amdrup Harbor, an eastern indentation of Rosenving Bay at the northern entrance to Scoresby Sound. The main settlement was established in 1925 on Ferslew Point, seen in the right background at the entrance to the harbor. Figure 91 shows the settlers at Cape Hope on the western side of Rosenving Bay. Two hunters are absent. (Photographs from Ejnar Mikkelsen.)

ditions that appear to prevail on the whole stretch of coast from 80° to 70° N. between the inland ice and the pack ice. The lowest absolute minimum of all three stations (Danmarks Havn, Sabine Island, Scoresby Sound) was even registered at the southernmost, Scoresby Sound, namely −47°. At the German station there was observed for the first time the great predominance and violence of offshore (northerly) winds, which from September to April blew almost exclusively, while from May to July sea winds prevailed on the whole, as also in Danmarks Havn. The effect of these winds was reflected in the landscape in many ways: in the rounding off of the larger stones on the northern side, in the north-south alignment of the smaller gravel, and in the corresponding parallel furrowing of the snow, from which one could take one's course in a fog.

The number of plant species is considerably greater here, and the vegetation more luxuriant, than in Northeast Greenland. Grass carpets, mosses, lichen, and heather, and, in addition, stunted bushes and flowers make up the picture. Pansch, who accompanied the second German Arctic Expedition, reports of Clavering Island: "Roundabout there flourished the most magnificent growth of grass, which was so high in places that the finest lawns in a park could scarcely equal it. From it protruded the finely developed flowers of *Poa* and other genera, as also here and there the yellow heads of the dandelion (*Taraxacum phymatocarpum*). Farther along, where the ground was more undulating and drier, the cinquefoil gleamed in thick beds or the fresh foliage of the *Oxyria* drew attention."

The animal world is the same as in the Northeast. Even the Arctic wolf, which is making great inroads upon the reindeer herds, has spread to this stretch of coast and has been met with as far south as Scoresby Sound. The musk ox has also been found on the wide heaths of Jameson Land bordering this sound. Throughout the fiord region old Eskimo winter houses have been found, in twenty-five settlements. In contrast, upon the basalt stretch south of Scoresby Sound only three such sites have been discovered. This coastal stretch was perhaps more difficult than Melville Bay for the Eskimos to pass in their migrations. Living Eskimos were last encountered by Clavering in 1822 in latitude 74½°, a dozen in number. Recent settlements are again being established in this region, especially since 1925 at the northern entrance to Scoresby Sound (Figs. 91, 92).

Jan Mayen

Very close to central East Greenland in position and volcanic nature lies the island of Jan Mayen. It is the most isolated and, with its 370 square kilometers, almost the smallest of the Arctic lands; but its volcano, together with some of Greenland's nunataks, belongs to

their highest mountains and is a landmark visible from afar. Presumably already known to the Norsemen, the island in the beginning of the seventeenth century, when England and Holland were competing in the whale fishery, was continually being discovered and named; and of the series of names given to it that one has finally persisted which commemorates the Dutchman Jan Jacobsz May. But before him Hudson appears to have seen the island in 1607. As early as 1616 the Dutch had begun to hunt whales here, which quickly brought

FIG. 93—Beerenberg volcano on Jan Mayen. (Photograph by P. Dusén, *Ymer*, Vol. 20, 1900, Pl. 5.).

active life to the solitary island, as is shown by a painting in the Amsterdam museum dating from the year 1639. After the extinction of the whale fishery the island was visited only at intervals and then chiefly by explorers. A new, very accurate map was prepared by the Austrian contingent of the International Circumpolar Stations.

Beerenberg, which was ascended for the first time in 1921, occupies the principal part of the island. It is still a slightly active volcano, eruptions of which are recorded as having taken place in the years 1732 and 1818. At its southern base lie parasitic craters. Masses of lava, bombs, tuffs, and volcanic sands cover the slopes. The summit is about 2500 meters high. Ice fills the great main crater and hangs over the edge as an unbroken cap which sends forth radiating glaciers, some of which extend down to the coast. Moraines follow along the edge of the ice border at different heights. Towards the southwest a narrow spur projects from the mountain. Its southeastern side, for the most part a flat sandy coast, is strewn with much driftwood. The spur itself is hilly and in material and form likewise reveals its recent volcanic origin.

The generally poor sandy and lava soil, the sharp winds, and the low summer temperature permit but scanty plant life. In addition to mosses, lichens, fungi, and algae there have been found over forty species of blossoming plants, frequent among which are *Ranunculus glacialis*, saxifrages, *Cerastium*, and a *Salix* which forms the only woody growth, occurring, however, in dense ramification. Higher animals

are represented by the Arctic fox and flocks of sea birds. The climate is entirely Arctic, especially with its wide temperature range in winter and small range in summer. However, in winter southeastern winds not infrequently break through. As a consequence the average of the coldest month, namely $-10°$ C., is, on the whole, not low. That of the warmest month, only $3.5°$, is typically Arctic. Characteristic of its situation at the mean limit of pack ice are its frequent fogs. The island seems to have been made for a weather station. The need for an observatory here was especially felt by Norway, and therefore in 1921 she erected a wireless station here, meteorological records having been started in September of that year. Although still a *terra nullius* Jan Mayen is considered by Norway to be within her sphere of interest.

THE ANTARCTIC

The Region As a Whole

Antarctic Exploration in Its Historical Development

Except for the fact that Australia and Japan have recently participated in Antarctic research by means of their own expeditions and Argentina by means of long-period records made at observatories established by her, the exploration of the Antarctic, like that of the Arctic, has been carried on by the peoples of Western civilization of the northern hemisphere. As a result of their distance from the field exploration has not been pursued in the Antarctic with the same persistence as in the Arctic; it was begun later and has been marked by interruptions. In spite of the progress of the last two or three decades, therefore, our knowledge of the Antarctic is by no means so detailed nor so uniform as that of the Arctic.

As a result of the hypothesis of a great southern continent, which goes back to Hipparchus, Marinus, and Ptolemy, possibly even to the Chaldean Seleucus, "Terra Australis" became the goal of expeditions for several hundred years after the beginning of the age of discovery. The earliest map bearing this name appeared in 1531. Exploration constantly reduced the size of this hypothetical land, but on these expeditions several of the sub-Antarctic islands were discovered, for example South Georgia as early as 1501–1502 by Amerigo Vespucci. It was James Cook who first completely swept away the illusion. He discovered the South Sandwich Islands on his second expedition of 1772–1775 but otherwise saw no land in the south in spite of a number of advances beyond the Antarctic Circle, on one of which he even reached latitude 71° S. He thus really defined the limits of the Antarctic. The conception of a great ocean now replaced that of a great land mass. It was nearly half a century after Cook that land was again sighted south of South America; the British sealers Smith and Bransfield discovered the South Shetland Islands, other sealers found the South Orkneys, and a Russian expedition under von Bellingshausen (1819–1821) came upon Peter I Island and Alexander I Land, i. e. land beyond the Antarctic Circle. A few years later the whaler Weddell reached latitude 74° 15′ in the sea named for him. The first discoveries of land in East Antarctica were made in the thirties by other whalers—Biscoe, Kemp, and Balleny.

But it was not until the brilliant period of 1838–1843, instigated by Gauss's work in terrestrial magnetism, during which no less than

ten vessels were under way, that longer stretches of coast line were discovered, by James Clark Ross, Charles Wilkes, and Dumont d'Urville, and their characteristic features disclosed. The peninsula of West Antarctica and the coast of South Victoria Land, together with the ice barrier in Ross Sea, were revealed, and to these were added the series of unconnected landfalls in East Antarctica from Cape Adare to Knox Land. To Ross himself we principally owe the main elements of our present conception of the Antarctic: the ice-covered land with its terrible storms, the high coastal walls with their mighty glaciers, the great volcanoes with their smoke banners high up in the snow-swirling air, and, not least, the ice wall that bears his name. The relationships, however, between the individual elements of the picture still remained quite incomplete.

Then for half a century nearly all interest centered on the extreme north. In the nineties the interest in the Antarctic Regions was reawakened by a number of whaling cruises, among them those in which Bruce and Larsen successfully participated, and also by Neumayer's scientific propaganda. The greatest advance was then made at the beginning of the present century as a result of four organically connected expeditions undertaken on the recommendation of the International Geographical Congress at Berlin in 1899, namely those of the *Scotia* under William Bruce, the *Gauss* under Erich von Drygalski, the *Antarctic* under Otto Nordenskjöld, and the *Discovery* under Robert Falcon Scott, together with their predecessors and successors, the *Belgica* under Adrien de Gerlache, 1897–1899, the *Southern Cross* under C. Egeberg Borchgrevink, 1898–1900, and the *Français* under Jean B. Charcot, 1903–1905. The field of operations of the *Belgica* and *Français* was on the western side of the peninsula of West Antarctica: here the *Belgica* was the first vessel to winter in the Antarctic and here it drifted from 70° to 100° W. longitude. In this region the *Français* carried out extensive coastal surveys and discovered a number of new lands. Borchgrevink spent the first winter in South Victoria Land, known since Ross's time, and advanced on the Ross Barrier ice to latitude 78° 50′. Here, too, was the field of activity of the *Discovery* expedition, on which Scott attained 82° 16′, crossed the high coastal range, and made an advance over the inland ice cap. The *Antarctic* under adverse circumstances made a thorough exploration of the eastern side of West Antarctica. The *Scotia* discovered Coats Land on the eastern margin of Weddell Sea. The advance of the *Gauss* was made in the Indian Ocean quadrant, hitherto the least known; on the coast of Kaiser Wilhelm II Land, which it discovered, observatory records of many kinds were made in connection with a branch station at Kerguelen. To supplement these expeditions uniform observations by vessels sailing south of latitude 30° S. were also arranged for. From all these large-scale expeditions and

their comprehensive scientific reports there resulted a clear conception of the existence of an Antarctic Continent and much fundamental knowledge as to its nature.

Since then exploration has not ceased; many additions have been made, and the south pole has been reached. The gateway for this feat was Ross Sea. Here Ernest H. Shackleton from 1908 to 1909 followed the coastal range of South Victoria Land far to the south over the ice barrier and attained a latitude of 88° 23′ S. on the plateau lying back of it, utilizing new methods of exploration, such as ponies and an automobile. By the same route Scott reached the south pole on January 18, 1912, from which he did not return and which the more fortunate Amundsen had already reached on December 16, 1911, on a route somewhat farther to the east over the same ice barrier.

Between the South Victoria Land coast and Kaiser Wilhelm II Land an Australasian expedition under Sir Douglas Mawson in 1911–1914 by means of extensive sledge journeys coördinated the scattered landfalls of previous explorers and carried out investigations at two permanent stations and at a branch station on Macquarie Island. In the region of Belgica Sea and Drake Strait Charcot conducted an expedition for the second time in 1908–1910. In Weddell Sea Wilhelm Filchner on the *Deutschland* in 1911–1912 came upon its southern margin, made up of Luitpold Land and an ice barrier joining it in latitude 78°. Two years later Shackleton pushed forward into this region on the *Endurance* in order to cross the continent to Ross Sea; but, like his predecessor's, his vessel was carried away to the north, during which drift the *Endurance* succumbed to the pressure of the ice and the party was finally rescued on Elephant Island. The *Aurora*, which was waiting for him in Ross Sea, likewise was caught in a northward drift in 1915–1916. On a new attempt to reach the same objective which he undertook in 1921, the daring leader died on South Georgia.

Thus the purely scientific exploration of the Antarctic is in full swing. Indeed, Antarctic expeditions have from the beginning had scientific rather than practical aims. The earliest motive here was the search for knowledge. It animated men like Cook and Bellingshausen; the whalers followed later; and scientific research is an ingredient, especially since the beginning of the present century, even of those among the many expeditions that are most governed by sporting aims. The results are correspondingly large and surprising in this latest brilliant period; the vastness of the Antarctic Continent is increasingly disclosed as a land area 1½ times the size of Europe or not much less than mainland Canada and the continental United States together, this land mass lying under a single immense smooth ice cap, which is only in places interrupted by mountains and which rises to elevations of 2000 to 3000 meters.

Conception, Limits, Size, and Articulation

The Antarctic consists of a polar continent surrounded by an ice-filled ring of ocean waters in which lie scattered island groups, partly of polar, partly of sub-polar character. On the whole it is therefore the antithesis of the Arctic. Also it is more compact, and its phenomena are more uniform and on a larger scale; its physical characteristics, its wind, temperature, and current conditions, as well as other phenomena connected with them in general exhibit a more closely latitudinal arrangement. To circumscribe the region, the ice limit, the tree limit, and isotherms may be used, as in the north. However, the 10° C. isotherm of the warmest month is not alone sufficient, as this would include Tierra del Fuego in the Antarctic. In keeping with Otto Nordenskjöld's suggestion (p. 73, above) it is better to take the annual isotherm of 0° into consideration also.

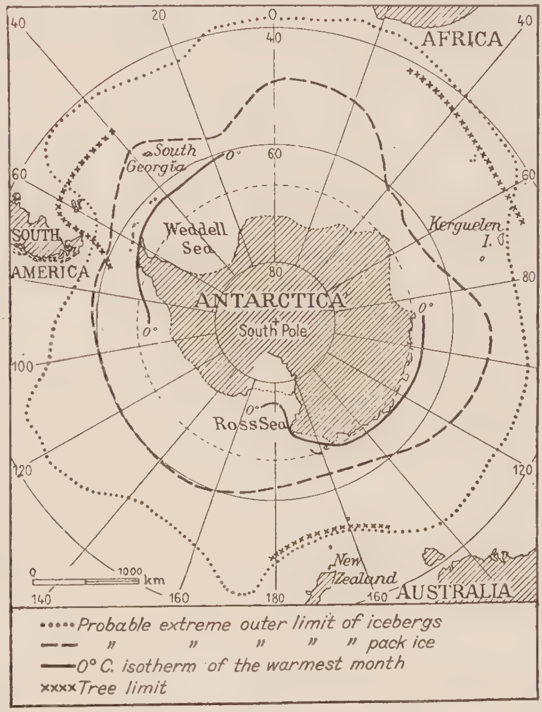


FIG. 94—Limits of a number of physical phenomena in the Antarctic. Scale, 1:145,000,000.

The Antarctic Continent is the only continent made in a single mold, as it were, for its surface consists almost entirely of ice and the underlying rock hardly appears. This unity is due to the vast inland ice, which at its outer border ends in walls, shelves, and tongues, sends forth icebergs, and everywhere within its influence calls forth an extremely continental climate with cold summers, bitterly cold winters, and violent snowstorms. Ice and climate also bring about uniformity of life to an extent that is nowhere else the case; everywhere there are the same birds, especially penguins, everywhere there are the same few species of seals and whales in the sea and on the ice, and even over large areas of the sea floor the bottom deposits reflect the influence of the ice. More even than in the Arctic the coast here must receive primary consideration in regional study and

description as well as in scientific field work. For only the coast exhibits a relatively wide variety of phenomena—variety of form and of climate—and only the coast is the abode of life. The interior is the greatest desert known on earth. As a result of the ice cap the elevation of the continent is far greater than that of all other continents; Meinardus calculates the mean altitude to be 2200 meters.

Where the coast has not yet been determined it may in general be assumed to lie just a little south of the farthest points reached, as the impenetrable ice belt generally is not far from the coast. Even if the coast line were determined the area of the continent could not be stated in as exact terms as in the case of the other continents, because it is often impossible to decide where the land ends and where fast-ice or floating ice begins. An area of 13,000,000–14,000,000 square kilometers doubtless approaches the truth closely. In relation to its size this land mass is very compact; it is surrounded by only few islands and small ones at that. The structural features are cast on broad and simple lines. The main articulation is brought about by the deep penetration of two embayments, which have also served as the gateways of exploration—Ross Sea to the south of Australia and Weddell Sea at the southern end of the Atlantic Ocean, the upper end of each being covered by an ice sheet. Extending around from one sea to the other, the whole eastern part of the Antarctic is occupied by an extremely compact land mass that obviously contains the center of gravity of the continent, whereas in the western part a peninsula projects tonguelike towards South America. The terminal part of this projection may be termed the peninsula of West Antarctica. Apart from this peninsula and the archipelagoes immediately in front of it the continent lies south of 65° S., i. e. almost entirely within the Antarctic Circle.

Because one region differs so little from another the subdivisions that have been proposed are primarily schematic. In addition to the division into East Antarctica and West Antarctica the division into quadrants, recently again suggested by Markham, has become current. Their nomenclature varies. More appropriate than the designation by personal names is that suggested by Canabich one hundred years ago into Atlantic, Indian, Australian, and Pacific quadrants.

Structure and Glaciation

Structurally the Antarctic Continent consists of two parts: in East Antarctica the Indo-African plateau type predominates, in West Antarctica the American-Pacific folded type. Both parts are joined under the ice carapace. The ice cap in the vicinity of the south pole is a plateau 3000 meters high, whence it descends to the margin of the continent, at first slowly and then rapidly. In many places it

reaches the coast in an unbroken front, sometimes even extending beyond in the form of ice sheets that rest on the continental shelf or float in the sea. Steep coasts are the rule, whether they be of rock or of ice. Relatively high mountains parallel the coast in South Victoria Land and the peninsula of West Antarctica, in the latter area as a continuation of South America, in the former as a volcano-studded fault margin of the plateau, which forms part of the Indo-African

FIG. 95—Sastrugi on Barne Glacier, western side of Ross Island, South Victoria Land. (Photograph by H. G. Ponting in C. S. Wright and R. E. Priestley: Glaciology, Sci. Repts. British (Terra Nova) Antarctic Exped., 1910–1913, London, 1922, Pl. 15.)

region. These (mountainous) north-south stretches of the coast contain the land areas that are freest from ice, i. e. the South Victoria Land coast of Ross Sea and both sides of the peninsula of West Antarctica. Where rock is exposed denudation is powerful as a result of summer insolation, frost weathering, and strong winds. The violent wind acts as a formative agency on rock and snow surfaces. It transports snow, dust, and sand; it creates small heaps of coarse detrital material like those in stony deserts; it polishes boulders and bed rock; it furrows the snow and shapes it into sharp-edged sastrugi (Fig. 95). The east-west stretches of coast are covered with ice to a much greater depth and more continuously than the north-south stretches and are also more closely beset by sea ice. For this reason it is more difficult to sail along them, as the history of Antarctic exploration shows.

The glaciation of the Antarctic Continent as well as of the Antarctic and sub-Antarctic islands was once greater than now and in

a number of places surely attained elevations hundreds of meters higher than today. Evidence of this is furnished by moraines, erratics, and *roches moutonnées* as well as by the "dead" ice in the valleys and coastal walls of South Victoria Land and especially by the areas of shelf ice off the coast at the Gaussberg, in Ross Sea, and along Luitpold and King Oscar Lands. The low-lying position of the continental shelf, 300 to 700 meters below sea level, agrees with this.

At present the recession of the ice, although with fluctuations, continues. Photographs taken on the *Discovery* expedition indicate many more bare surfaces than Ross's sketches, and the ice barrier has on the whole retreated since his time, although since the beginning of the twentieth century it has been advancing. At the Gaussberg a diminution of the thickness of the ice by evaporation has been established. In spite of all this, Antarctic glaciation is still so intense today that to find its counterpart in the northern hemisphere one must go back to the Pleistocene. The snow limit frequently lies at sea level, even north of the Antarctic Circle. For this reason the surface of the glaciers is almost everywhere free from débris, as the material that may come from above is again covered by snow and incorporated as an internal moraine. Thus the ice almost everywhere has an alimentation area to draw upon; only in places along the margin are there dissipator areas, and the wastage here takes place not by melting but by ablation.

The form of glaciation is that of continental inland ice. Even if in the marginal belt other types are sometimes developed, such as normal valley and piedmont glaciers, they are to be interpreted only as parts, modified by the substructure, of the great mass of the inland ice as a whole. The inland ice moves slowly towards its periphery, at the Gaussberg at the rate of 150 meters a year. It even advances over the sea and creates a new type, the shelf ice. Frequently it pushes out into the sea in long tongues. It attains its maximum size as a feature of the landscape at the two points where the sea penetrates farthest into the continent, namely at the southern ends of Weddell Sea and Ross Sea, in the form of the well-known ice barrier.

The shelf ice, as projected or sloughed-off inland ice, in its internal structure exhibits the same stratification, banding, and cleavage as the inland ice. It may also first develop in sea water or be augmented by accretions of new snow on floe ice or on projected land ice. Often it bears evidence of great age in the form of polished, rounded surfaces, called blue ice by von Drygalski. According to its properties the shelf ice is partly related to the inland ice, partly to the drift ice, as indeed the continental shelf itself is a transition between the continent and the deep sea. The continental shelf stands under the dominance of the ice, not only because it is covered by shelf ice but also because it partially owes its shape to that ice and because the sea

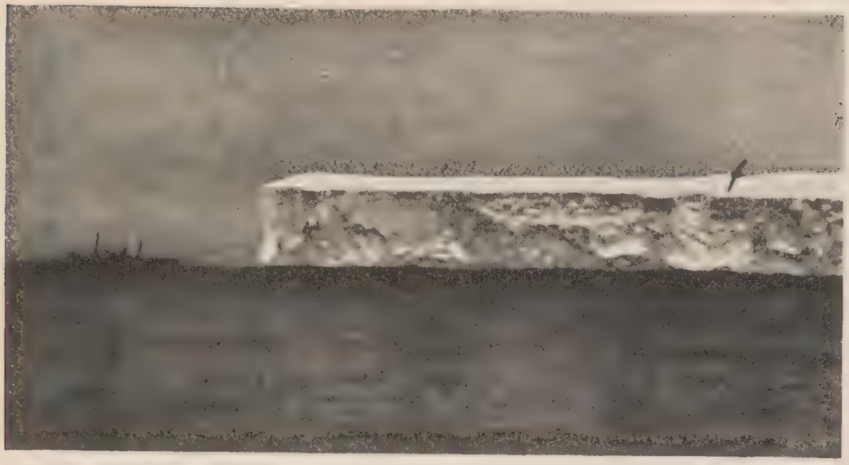


FIG. 96

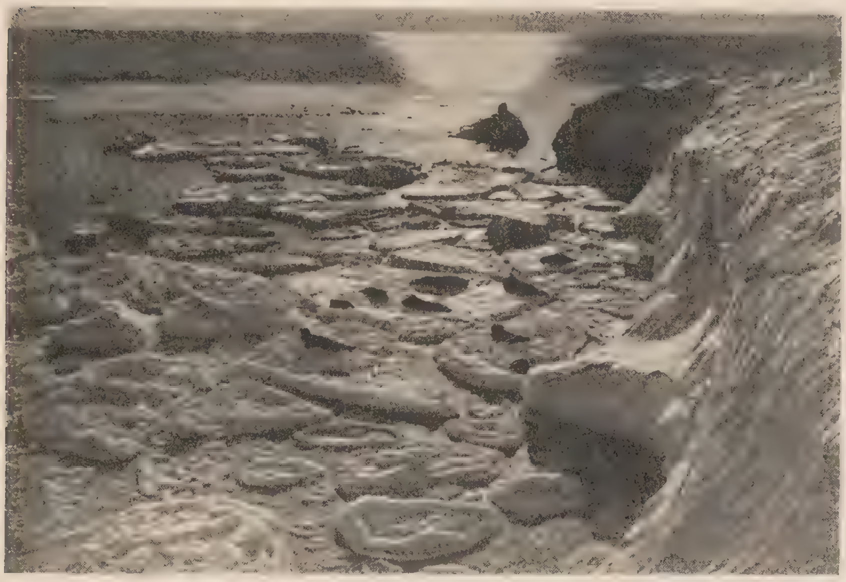


FIG. 97

FIG. 96—Tabular iceberg of the Antarctic (latitude 55¾° S., longitude 29½° E., between South Africa and the Antarctic Continent). *Valdivia* on the left; to the right, an albatross on the wing. (From Carl Chun's "Aus den Tiefen des Weltmeeres," Gustav Fischer, Jena, 2nd edit., 1903, p. 219.)

FIG. 97—Newly formed pancake ice in McMurdo Sound off Cape Evans, southwestern side of Ross Island. Seals basking on the ice. (Photograph by H. G. Ponting in his "The Great White South," Robert M. McBride and Co., New York, 1922, opp. p. 104.)

water over it has a temperature close to the freezing point generally down to the bottom and, finally, because the life in that sea is polar in character.

In addition to the inland ice and the shelf ice there is drift ice. These three types locationally are respectively related to the land,

the continental shelf, and the deep sea. The drift ice consists of icebergs and floes of sea ice. The former are relatively more in evidence in the Antarctic than in the Arctic, as they are developed along the whole circumference of the coast. Drygalski once estimated that he could see nine hundred icebergs at one and the same time. Both categories of drift ice are formed out of snow, as the sea-ice floes, although originating through the freezing of water, grow through the accretion of snow, whereas they melt on their undersurfaces.

The icebergs come both from the inland ice and from the shelf ice; in the latter case they have a looser and more snowlike structure. They occur in three types, one original and two derived. The first is the tabular or box form, 30 to 40 meters high and tens of kilometers long (Fig. 96). Through weathering this normal type while drifting gradually assumes more irregular shapes. On the other hand if the icebergs lodge on shoals and are scoured by the winds, as is the case especially in East Antarctica, there develops the third type, that of the blue icebergs.

The floes of sea ice through freezing grow to a thickness of nearly 2½ meters if there is little snowfall. Even those that have been enlarged by snowfall rarely go beyond 8 meters in thickness; 15 meters is the absolute maximum. As a result of pressure the floes often have raised rims and are round in shape; they are then called pancake ice (Fig. 97). High piles of pressure ice such as those in the Arctic occur less frequently, because the drift ice disperses radially from the continent and proceeds into a constantly widening area. Even where there is more cause for pressure, as in Weddell Sea especially, the pressure ridges do not become nearly as large as in the Arctic; they attain heights of 4 to 6 meters only. Melt-water lakes on the ice fields are also infrequent here; destruction takes place mechanically through wave action.

In contrast to the drifting sea ice the coast is as a rule accompanied by an ice foot, i. e. a narrow ledge of sea ice several meters thick that forms in the tidal zone. On the other hand a broad belt of open coastal water is generally lacking, as effective thawing in summer does not set in because of the below-freezing temperatures even then prevailing. For this reason no vessel has yet been able to stay in sight of land for any length of time along the east-west stretches of coast; the closer one approaches the land, the denser does the belt of ice become.

Climate

The ban of the ice is hardly broken even in summer. It is noteworthy that the mean temperature of the warmest month is practically always below freezing. Whereas in the Arctic only two small areas, one at the pole and the other in Greenland, are enclosed by the

0° C. isotherm of the mid-summer month, here the whole great continent is so enclosed (see map, Fig. 94), and the various sledge journeys to the pole revealed individual temperatures of −50° even at the time of the year when insolation is continuous. Thus a continental climate with cold summers is the most characteristic attribute. There is very little thaw; no flowers blossom in the landscape; there is no sound of rushing torrents; there are no swarms of insects nor of bees and butter-

	Latitude	Longitude	Mean Temperature (C.)		
			Warmest Month	Coldest Month	Year
Framheim	78° 38′	169° 37′ W.	−6.0° (Dec.)	−38.0° (July)	−26.0°
McMurdo Sound	77° 51′	166° 45′ E.	−3.9° (Dec.)	−25.9° (July, Aug.)	−17.4°
Cape Adare	71° 18′	170° 9′ E.	−0.2° (Jan.)	−25.8° (June)	−13.9°
Gauss Station	66° 2′	89° 38′ E.	−0.9° (Jan.)	−21.9° (Aug.)	−11.5°
Snow Hill	64° 30′	56° 56′ W.	−0.9° (Jan.)	−20.8° (July)	−11.8°
Wandel-Petermann Is.	65° 7′	65° W.	1.0° (Jan.)	−13.0° (July)	−4.1°
Laurie Island	60° 44′	44° 39′ W.	0.3° (Feb.)	−12.4° (July)	−4.6°
South Georgia	54° 13′	36° 33′ W.	5.5° (Feb.)	−2.1° (July)	1.9°
Kerguelen	49° 25′	69° 53′ E.	7.0° (Feb.)	0.4° (July)	3.2°
Campbell Island	52° 23′	169° 8′ E.	10.0° (Feb.)	4.5° (Aug.)	6.7°
Mean Values Along	60°		1.2°	−10.3°	−4.1°
Parallels Indicated	70°		−1.3°	−23.9°	−13.3°
(according to Mein-	80°		−7.0°	−36.0°	−25.0°
ardus)	90°		−11.0°	−42.0°	−30.0°

flies, as is the case even in northernmost Greenland. Otto Nordenskjöld even found that the snow cover increased in summer. Only where volcanic sand and dust fall on the ice does thawing become of any consequence. The main reason for the cold of the summer is the glacier ice, which down to a depth of one meter proved to be at least 3° colder in summer than a soil layer of the same depth. Solar radiation is, however, intense—so much so that it can burn the skin. "The weather sides of the ponies were quite dry, but their lee sides were frosted with congealed sweat" (Shackleton). The summer is short. The relatively higher temperatures generally occur only in December and January; before and after, the curve falls abruptly and then for the six winter months fluctuates about a low mean value. The curve of the annual march of temperature therefore has the form of a trough.

The winter temperature is not as low as in large parts of the Arctic and the adjoining regions. The five-year July average at Framheim on the Ross Barrier amounted to −38° C.; at McMurdo Sound it is more than 10° higher. As to individual values, too, the low minimum temperatures (nearly −60° C. is the lowest recorded) are less characteristic than the low maximum temperatures. Neverthe-

less the severity of the climate nowhere finds its equal, because the—after all—low temperatures are accompanied by extremely violent winds—the effect of a temperature of –40° coupled with a wind velocity of 30 meters per second is almost beyond belief.

Temperature inversion due to elevation is very great. At McMurdo Sound, on the occasion of a pilot balloon ascent to 4500 meters, the temperature was found to be only 5° lower at that height than on the ground. For this reason a much lower temperature prevails in winter in the Ross Sea region when a south wind of medium velocity is blowing than when there are storms, because in the latter case the cold ground air is completely swept aside and replaced by warmer air from above. Calms bring the lowest temperatures. As to variability the uniform coast of East Antarctica differs from all the others; it has more stable, the other stretches of coast more fluctuating conditions. Thus mid-summer temperatures of –25° have occurred in the Ross Sea region; the highest temperature of the year was recorded in the midst of winter at Snow Hill; and at Framheim August attained a mean diurnal variability of 7.3°. It is the wind primarily that determines the amount of warmth, and the fact that the winds in East Antarctica are particularly constant explains the more uniform temperatures in that region.

As to wind direction, a general concentration on one direction or several closely related directions is the rule along the margin of the Antarctic Continent; thus at Snow Hill west winds prevail for 34 per cent of the time; at McMurdo Sound southeast winds for 42 per cent; at the Gauss station east winds for 55 per cent. This direction in general runs parallel to the coast, so that, as a whole, for the margin of the continent one may assume a belt of east winds. At some distance beyond in lower latitudes vessels have always met with greater changeability of wind direction; here, between 65° and 55°, lies the zone of the "sub-Antarctic variable winds" (Meinardus)—this being really the trough along which travel the barometric lows that are adjoined on the north by the belt of "brave west winds," or "roaring forties."

Along the continental margin the prevailing directions of the storms are as a rule the same as those of the winds. As to the duration, intensity, and frequency of storms, the Antarctic has no counterpart elsewhere on earth. Even if the annual mean of the wind velocity is for the most part not much greater than along many stretches of coast in the Arctic, the individual storm is far more intense. At McMurdo Sound squalls of 35–45 meters per second have been experienced, in Adélie Land even of 90 meters per second. The change to calm is often abrupt when the wind ceases to blow from the prevailing direction. Locally, also, the storms may often be limited abruptly as if by a wall. Mawson reports as follows on the frequent whirlwinds

of varying extent observed in Adélie Land: "The radius of activity of these 'whirlies' was strictly limited, objects directly in their path only being disturbed. For instance, Laseron one day was skinning at one end of a seal and remained in perfect calm, while McLean, at the other extremity, was on the edge of a furious vortex. Travelling over the sea the 'whirlies' displayed fresh capabilities. Columns of brash-ice, frozen spray and water-vapour were frequently seen lifted to heights of from 200 to 400 feet, simulating water spouts." The closer to the coast and particularly to the higher land an observation station may be, the more storms does it experience. When these violent storms fill the air with thick snow, they are called blizzards. They are the most terrible trial of sledge parties, and their description runs like a red thread through the literature of Antarctic travel. The successful battle with these elemental forces may well be said to be the culmination of what human will power, sacrifice, and steadfastness have accomplished in the conquest of the earth. "Blizzards are our bugbear." Thus writes Scott in monumental brevity on his return march from the pole. Only 20 kilometers from the depot that would have spelled salvation he was overwhelmed by a final hurricane which held him and his companions four days in their tent and ended the lives of these men who had already been tortured by hunger and cold in the storms that had previously followed one another almost without interruption.

The predominantly easterly winds which blow parallel to the coast of Antarctica were formerly interpreted as issuing from the continental anticyclone. But according to the view of Meinardus, which, to be sure, is not unopposed, they are rather parts of the rotational motion about the barometric lows which sweep by in the depressional trough that lies in front of the continent; they are therefore the opposite of the west winds which blow north of this depressional trough. Particularly their warmth and humidity point to this conclusion. The great constancy of these circumpolar winds may be due to the fact that the cold stratum of air along the margin of the continent has a tendency to flow outward and therefore acts as a regulating wall. Farther inland, however, the continent is hardly overlain by higher pressure; rather, because of its altitude, it projects upward into the polar whirl of the general circulation, which thus probably brings precipitation to the interior and provides the source of supply for the inland ice. Along the margin of the continent atmospheric pressure varies according to the nearness of the depressional trough at any given time. The mean annual circumpolar value of barometric pressure is very low, 740–745 millimeters. The closer to the core of the whirl the more fluctuating do pressure and weather conditions become; in the latitude of Kerguelen the mean hourly variability of atmospheric pressure is 0.47 millimeter, at the Ross Barrier only 0.20 millimeter.

In accordance with their cyclonic character the winds of the marginal zone bring ample precipitation and in part feed the inland ice. Fundamentally, the whole continent is an area of alimentation but not uniformly throughout; the winds distribute the snow in drifts, and on some areas of the continental margin more is blown away than is precipitated. Although measurement is difficult the following amounts of precipitation are probable: 800 millimeters at the Gauss station, 200–250 millimeters at McMurdo Sound, only about 100 millimeters in Weddell Sea, about 350 millimeters on the west coast of West Antarctica, more than 600 millimeters in Belgica Sea. Precipitation seems to take place more frequently in summer than in winter. Accumulation also is greater in summer; ablation is greater in winter, with its storms that sweep large amounts of snow out to sea. Rain is rare in East Antarctica, more frequent on the western side of the West Antarctica peninsula, which is more exposed to the influence of the west winds. Also the snow is not often soft and fleecy; rather it is as a rule fine and dry like sand. When no snow is drifting the ice and sky appear in brilliant pure colors, especially when the aurora australis, which occurs with increasing frequency in the winter months, displays its draperies and sinuosities in the sky in an inexhaustible variety of form and color. The aurora does not occur in the projecting part of West Antarctica.

As to the climate of most of the islands the far side of the barometric depressional trough, with its constant west winds, is determinant. These west winds bring about generally low temperatures, small amplitudes, severe storms, and heavy precipitation—as a whole, an oceanic climate with cold summers. Owing to these characteristics some of the islands differ from the continental margin to a considerable degree.

The currents correspond with the easterly winds immediately along the continent and with the westerly winds farther out. They thus substantially form a double ring around the Antarctic Continent: a westerly current near the coast and an easterly current in lower latitudes. The former bends into the latter, so that on the whole both currents combined allow polar water to flow out into the lower latitudes. But in embayments such as Ross and Weddell Seas they become a circulatory system rotating clockwise Aside from these subsidiary tendencies of water exchange in a meridional sense, the predominating direction is that along the parallels of latitude. That is likewise reflected in the course of the water isotherms and ice limits. The latter in turn have an influence on the bottom deposits of the sea, which, in the pack-ice zone, abound in indiscriminately mixed coarser and finer rock fragments but which are poor in organic remains, whereas such remains become very frequent along the ice edge and form the globigerina and diatom ooze.

Antarctic Life

To the ice and climatic conditions, especially the low summer temperature, corresponds the dearth of the whole continent in land plants—a dearth which is unique even when compared with the plant life of Greenland. The present scarce flora seems to be of postglacial age. So far as animals occur, their basis of life is in the sea; they are foreign to the interior of the land because there nourishment is lacking.

FIG. 98—Animal life in the Antarctic on a fine summer's day: seals and Adélie penguins in the Mackellar Islets (off Adélie Land, 67° S. and 142⅔° E.) (From Mawson's "The Home of the Blizzard," William Heinemann, London, n. d., Vol. 2, opp. p. 256.)

Passarge characterizes the flora, which is sparse and occurs only in places along the margin of the continent, as a sort of impoverished tundra. Not a single flowering plant has been found within the Antarctic Circle, and grasses do not occur south of latitude 62° S. Of moss species over sixty are known and of lichens over one hundred, half of which also occur in the Arctic. Algae color the snow; they also occur on damp ground and in water, especially in the sea. These number about four hundred species in the Antarctic and sub-Antarctic. The land fauna, too, consists of lower forms. The resistant rotifers are able to survive in the ice even against extreme cold. The large land mammals of the high north, however, such as the reindeer and musk ox, are lacking.

In contrast the sea and its ice exhibit an enormous abundance of life, which in part overflows on to the coast but nevertheless always remains based on the sea. "As if nature had wished to impart also a sympathetic trait to this stark waste, it has populated the cliffs and the ice fields and icebergs that lie before them with thousands of penguins. On the pack ice lie great numbers of seals, the icy water is

furrowed by schools of whales, and in it are fishing swarms of stormy petrels, often whirling upwards like white clouds, while the great albatross, with motionless wings, soars about the vessel in circles" (C. Chun). When with the increasing height of the sun above the horizon the landscape is called to new life, it is consequently not through the blossoming out of the vegetation as in the Arctic, but rather the appearance of a greater quantity of animal life, especially of birds (Fig. 98), that constitutes this rebirth.

This wealth of animal life is based on diatoms; their abundance is characteristic of Antarctic waters, and their remains cover the sea bottom. Decomposition is reduced to a minimum in this water whose temperature always hovers about the freezing point; this food supply therefore is preserved fresh—indeed, it is so abundant that it colors the water brown. Diatoms are the food of the lower animals, such as crustaceans; these in turn are devoured by the crab-eater seals, penguins, storm petrels, snowy petrels, and many larger and smaller species of fish. The fishes are eaten by the seals, penguins, gulls, and petrels, and on many of these animals in turn live the largest sea mammals. As compared with the abundance in individuals of all these forms of life the number of species is not large.

The coasts are enlivened most by the penguin (Fig. 19, p. 67), that amphibian bird whose origin probably goes back to the Tertiary and which survived the complete glaciation of the continent by a high degree of adaptation to this region, although by means of the cold currents it has extended its range to the west coasts of Africa and South America and even to the tropics. On ice-free surfaces these birds form colonies of many thousands of individuals. Droll in their human-like sociable behavior, in their curiosity, and their oddly skillful motion on ice and land as well as in and over the water, they have become the special friends of all Antarctic explorers and have helped most to relieve the monotony of an Antarctic sojourn and the bleakness of Antarctic surroundings. The principal species are the emperor penguin, the king penguin, and the Adélie penguin. The habitat of the king penguin is north of the Antarctic Circle, the Adélie penguin is most frequent along the whole border of the Antarctic Continent, but fondest of the cold is the proud emperor penguin (*Aptenodytes forsteri*), which therefore prefers South Victoria Land and East Antarctica and is lacking in the northern part of West Antarctica. It broods in mid-winter, in the coldest part of the Antarctic, and not on the land but on the sea ice.

Of the members of the seal family, which here differ from the Arctic forms, the most remarkable species, the sea elephant, only occasionally visits the Antarctic coasts and has already been almost exterminated by ruthless slaughter on the sub-Antarctic islands. The Ross seal, which lives on the pack ice, has also become rare. The

most common species are the Weddell seal, the crab-eater seal, and the strong and agile sea leopard. Whales are represented in a number of species. The whale fishery has done much for the exploration of the Antarctic, but heavy inroads have already been made in the number of whales. Of the southern right whales of Ross Sea, whose discovery by Ross attracted the whale fishery to these waters, none was met with on the *Discovery* expedition at the beginning of the present century. At present whaling is carried on primarily in the Atlantic quadrant of the sub-Antarctic, although to a certain extent it has again been taken up in Ross Sea.

FIG. 99—A male sea elephant on tussock grass, Macquarie Island. (From Mawson's "The Home of the Blizzard," Heinemann, London, n. d., Vol. 2, opp. p. 207.)

Sea animals as well as birds exhibit a zonal arrangement in the distribution of species that corresponds to the oceanographical conditions. When the first ice comes, the Antarctic petrels *Pagodroma nivea* and *Thalassoeca antarctica* generally put in an appearance; in the heavy floe ice are entirely lacking the life forms that accompany the west wind drift; and on the border of the continent the penguins remain almost the sole masters. The plant life of the sea is also arranged in latitudinal belts and can primarily be subdivided into an Arctic and sub-Antarctic zone. The boundary between both lies about in 60° S., as does the limit of drift ice.

The sub-Antarctic islands, in contrast to the Antarctic Continent, have a number of flowering plants; mosses and lichens predominate, however, and form tundra associations. In addition on several islands tussock grasses and, in the Kerguelen region, cushion formations dominate the landscape and create the aspect of sub-polar meadows. Characteristic of the coastal waters is the border of seaweeds, among them the giant fucus (*Macrocystis pyrifera*). Animal life is here represented by penguins, ducks, cormorants, petrels, Cape pigeons, sea elephants (Fig. 99), and sea leopards, as well as by insects and worms. Especially characteristic are the king penguin and the sea leopard. The whalers collect the penguin eggs as food.

Primitive man is entirely lacking on the continent as well as on the islands, including the sub-Antarctic; hence the Antarctic occupies an exceptional position in this respect among all continents and zones. That man was not able to migrate there by way of the ends of the southern continents and hence was not able to develop a polar race

similar to that in the north is fundamentally due to the position and the surroundings of the Antarctic, which present conditions of unexampled severity for crossing. The southern continents taper down to ends that are lost in a watery waste in which there are no tendencies facilitating a north-south exchange or connection, as in the Arctic, but which on the contrary is controlled by a wind and current system far more closely adhering to a latitudinal arrangement, that thus lays a ring, or rather a double ring (west-wind and east-wind belts), around the continent and shuts it off. In addition there are the general inhospitable nature of the continent itself, the almost complete ice covering, the unequaled summer cold, the in part impenetrable pack ice belt, and the incessant storms, during which many an expedition has had to carry on the greater part of its activities. The only stretch of coast that might be suitable for modern settlement seems to be the western side of the West Antarctica peninsula. According to atmospheric and oceanic circulation worked out by the writer in the scientific results of the *Gauss* expedition, a favorable condition similar to that in West Spitsbergen here exists in tendency if not in degree.

Much more suitable for modern permanent settlement are the sub-Antarctic islands, especially those of the Indian Ocean and South Georgia. A number of these island groups have already served as whaling headquarters during the nineteenth century for considerable periods of time. That settlement has here not developed in a more stable way is due alone to the great distance from the northern centers of civilization.

The whale fishery, whose renewed growth dates from the beginning of the present century, has brought about plans for and beginnings of a development in this region and, particularly, has led to the establishment of political suzerainty. France has extended her sovereignty over Kerguelen, over the Crozet group, and recently over Adélie Land, while Great Britain has taken possession of the greater part of the Antarctic Continent by declaring in 1908 and 1917 the whole Weddell Sea and West Antarctica sector to the south pole to belong to the Falkland Dependency and by creating the Ross Dependency in 1923, which comprises South Victoria Land and Ross Sea. Within these two dependencies lie the main whaling grounds, so that the whale fishery, which is mainly carried on by Norwegians, is dependent on British control.

The Individual Regions

The South Polar Plateau

The rock structure of the interior of the Antarctic Continent is hinted at only by the moraines of the marginal regions, especially those of the coast of East Antarctica. The rocks chiefly consist of

granite, gneiss, and crystalline slates. The surface of the interior everywhere consists of inland ice. One is justified in making such a statement because of the ice walls and ice cliffs that have been met with all around the coast and especially because of the findings of the sledge expeditions, even though these were restricted to the narrow north-south strip along Ross Sea and to the land lying back of the South Victoria coast. The inland ice is a plateau; in detail it may be further subdivided. This plateau ends in high marginal mountains along the western and southern border of Ross Sea. Elsewhere the inland ice generally ends seaward in a slope which begins relatively not far from the coast and gradually increases in steepness to an abrupt wall 40 to 50 meters high at its edge.

The highest point of the ice plateau is, so far as we know, in the vicinity of the south pole, with an elevation of nearly 3000 meters. In latitude 78° west of McMurdo Sound the height of the plateau is about 2500 meters, and at the magnetic pole in latitude 72½°, 2200 meters. Viewed as a whole its aspect is that of a limitless even plain of ice and snow. In detail the surface alternates between soft snow plains and undulations, firmer thin snow crusts, and hard sastrugi (Fig. 95) which are etched out by the winter storms and sometimes produce sharp ridges as much as two meters high and sometimes more rounded forms. In the marginal zone crevasses and clefts occur in abundance, small moraines occasionally. Its stratification the inland ice owes to the snowfall. As a result of the intense cold and the only slight summer warmth the plasticity and movement of the ice are very small; the latter amounts to 100—500 meters a year. Internal changes are therefore also slight, and the ice reaches the margin rather in the form of cemented snow than as glacier ice. Banding is only developed in the lowest parts. There are still many problems to be solved with regard to the ice plateau, particularly those concerning the relation of accumulation to dissipation.

This vast ice surface is the most intensely cold region of the earth. Even in the marginal zone of East Antarctica that lies along the Antarctic Circle the cold quickly increases inland. In this region at an elevation of 900 meters the snow temperature, which may be taken to correspond with the mean annual temperature, was determined by Mawson to be −27° C. The mean temperatures observed in the neighborhood of the pole were as follows: December, −22.6°; January, −28.2°. Reduced to sea level these temperatures are still about 10° lower than those of the corresponding summer months at the north pole. The mean annual temperature I estimate according to the observations at Framheim and the sledge expeditions to the pole to be certainly less than −30°, perhaps even less than −35°. The winds on the plateau come from southerly directions in the Ross Sea sector and are of great strength.

South Victoria Land

Between the meridians of 160° and 170° E. a high marginal range runs almost directly south from latitude 70° to the vicinity of the pole and then bends off towards the southeast. Except for its northernmost section and beginning in latitude 72° it consists broadly of two flat arcs concave to the east that meet in latitude 78°. The average elevation of this mountain range may amount to 2800–3000 meters; the highest peaks exceed 4000 meters and in the extreme south approach 5000 meters. This narrow mountain belt is South Victoria Land. To the west it slopes off gradually into the lofty ice plateau; to the east it descends as a rule abruptly to Ross Sea and to the Ross shelf ice. Along the foot of these high mountain walls and directed by them lay the routes of the British Antarctic expeditions, in the northern section in ships, south of latitude 78° on the shelf ice. This mountain belt, like the coast ranges of eastern Australia, is only the upwarped fault margin of the plateau, or else, for long stretches, a horst enclosed between faults parallel to the coast. Other fractures break it up transversely and create wide glacier-filled valleys.

In front of the coast lie recent volcanic islands, especially where the longitudinal and transverse faults cross. The footing of the coastal wall consists of gneisses, granites, mica schists, and thick beds of Cambrian limestones with granitic intrusions. Over these lies the Beacon sandstone, in places attaining a thickness of 600 meters, unfolded and occurring at most places along the coast. It probably dates from the Paleozoic. It includes a number of coal seams and is often interrupted by diabase dikes or covered by diabase sheets which perhaps date from the Cretaceous. Pronounced horizontal structure predominates, and for this reason the plateau form is a widespread characteristic. The great marginal faults and the volcanoes in their wake were developed during the Tertiary. There is evidence that in places along the coast recent movements have taken place, namely a positive displacement of the strand line in the not remote past, followed by a smaller negative displacement.

There may be a causal connection between the parallel marginal faults and the phenomenon which may be observed in following the coastal outline in detail, namely, from the vicinity of Cape Adare in about latitude 71° to the Conway Range in 79°, a progressive southward recession *en échelon* of the individual stretches of the coast from the 171st to the 160th meridian of east longitude. Beginning at Tucker Bay near latitude 73°, the land projection bounding it on the north turns in at right angles from the 171st to the 170th meridian. Just to the south of this, at Cape Phillips, this bending back at right angles is much more pronounced, namely from the 170th meridian in a straight east-west direction to the 167th meridian. Lady

Newnes Bay resulting therefrom is further enclosed by volcanic Coulman Island. In the next two reëntrants, Wood Bay, the smaller, and Terra Nova Bay, the larger, the coast line has already receded beyond the 164th meridian. South of the far-projecting Drygalski Glacier Tongue Geikie Bay attains the 163rd meridian, which, except for the further interruption of the Nordenskjöld Glacier Tongue, is thence followed by the coast line nearly to McMurdo Sound. In the vicinity of this sound, in part a young volcanic area, the land once more stretches forward to the east, until south of the long tongue of land projecting from Mt. Discovery it again bends back sharply in an east-west direction and reaches the 161st meridian in right-angled Moore Bay and, just south of it, the 160th meridian. The coast then follows this meridian, beginning with the Conway Range, across the wide Barne Inlet, to the latitude of the lofty Mt. Albert Markham (about 81½°) and then gradually bends to the southeast and forms the southern limit of the Ross barrier ice.

Back of the coastal walls, which often have a sheer height of several hundred meters, the land further rises abruptly to form high mountains and ranges, the larger and more continuous of which are the following: the Admiralty Range in the north, the Prince Albert Mountains north of McMurdo Sound, the Royal Society Range south of it, and, at the southern end of the Ross barrier ice, the Queen Alexandra Range west of the Beardmore Glacier and the long Queen Maud Range to the east and beyond. But some smaller mountain sections are also prominent, especially when they lie between wide debouching glaciers, for example the Mt. Nansen massif back of Terra Nova Bay, the Conway Range south of Moore Bay, and a little farther south the Britannia Range between the great Barne Glacier and its neighbor to the north.

The height of the individual mountains is least in the north, except for the Admiralty Range, whose altitude is 3000 meters, and increases southwards. In the Nansen massif Mt. Nansen is nearly 2500 meters high, and Mt. Melbourne in front of it about 2500 meters. Similar altitudes are attained by several summits in the Prince Albert Mountains. Between McMurdo Sound and Moore Bay there are giant peaks about 3000 meters high, and Mt. Lister and Mt. Erebus are 4000 meters. Farther south 3000 meters altitude is exceeded frequently, thus by Mt. M'Clintock and Mt. Albert Markham, each about 3200 meters. In latitude 83° the Markham Mounts even attain 4570 meters, and equal or greater heights occur in the Queen Maud Range.

At intervals the coast is accompanied by volcanic formations, generally recent but sometimes of different ages. Petrographically they belong to the Atlantic group throughout, whose main representatives are basalts, trachytes, and phonoliths. Such volcanic areas

are the Balleny Islands to the north, the vicinity of Cape Adare, Coulman Island, Mt. Melbourne, and especially Ross Island and its neighborhood. This island consists of four volcanic cones. South of it there are a number of smaller volcanic islands and, on a projection from the mainland, the volcanic Mt. Discovery (2770 meters).

FIG. 100—Ice ramparts at the foot of the ice mantle covering Mt. Erebus, Ross Island, seen from the southwest, with the peak itself in the background. (From "Scott's Last Expedition," Vol. 2, Dodd, Mead, and Co., New York, 1913, opp. p. 240.)

Into the gaps between these land pillars the Ross barrier ice penetrates, and its here low cliff edge bounds a wide bay on the south, namely McMurdo Sound. This protected bay, enclosed between the mainland, Ross Island, and the Ross barrier edge, has served as the main base of British Antarctic exploration. Here lies, overtowered by the gigantic Mt. Erebus as if by an immense monument, one of the most favorable and special localities of the whole Antarctic region. Although far advanced in latitude, still it can be reached by ship every year with reasonable certainty. In all directions there are tempting opportunities for sporting undertakings of the first rank—following the barrier ice as well as the coastal ranges north and south, climbing the gigantic glaciers and the high plateau margin, ascending Mt. Erebus, advancing to the southern magnetic and mathematical poles—and manifold problems present themselves for scientific research of the highest order.

The volcanoes of Ross Island consist of basalts of all kinds, dolerites, phonoliths, and trachytes. The four cones are called Mt. Bird, Mt. Terra Nova, Mt. Terror (3300 meters), and Mt. Erebus (4077 meters). Mt. Erebus (Fig. 100) rises to its great height at the juncture of two major fault lines. It was so named in 1841 by James

Clark Ross after the famous flagship of his expedition, and a party on Shackleton's expedition in 1908 successfully accomplished the difficult ascent of its peak in the rarefied, cold air and over abrupt rock precipices and snow fields covered with sharp-edged ridges of sastrugi, that also at these elevations indicate the direction of the predominant, violent winds. The mountain consists of three concentric and superposed craters. From the surface of the sea the slopes first rise gently, then more and more abruptly to the first, oldest, and largest crater; of its outer rock lip a remnant is clearly visible at an elevation of 2000 meters. Along the bottom of the slope moraines extend up to an elevation of 300 meters above sea level. Above this, to about 1600 meters, there follows a dense mantle of ice and snow from which white blanket black masses of lava or parasitic cones project abruptly here and there. Above this the slope, at first again concave in profile, rises to the second or main crater. Dark rock cliffs stand alongside each other at intervals, with steep snow slopes issuing forth between them; they resemble buttresses supporting the main crater. This crater has an elevation of 3450 meters. From it the uppermost, active cone rises to a height of 4077 meters.

This youngest crater is 800 meters wide and 275 meters deep. On its slopes pumice and lava alternate with snow. From three vents in its floor hissing clouds of steam, often glowing, are emitted to the accompaniment of sulphur smell. A unique phenomenon, due to the climate, are the ice fumaroles on the slopes. They are ice formations resembling the siliceous deposits of geysers. They occur in fantastic shapes green and white in color, being derived from the steam exhalations and forming accretions around the fumarole openings. During Shackleton's expedition almost uninterrupted activity was observed in the winter months, and the column of steam at times shot upwards for 1000 meters before it began to spread and enter the wind currents. "It became quite an ordinary thing to hear reports from men who had been outside during the winter that there was a 'strong glow on Erebus.' These glows at times were much more vivid than at others. On one particular occasion, when the barometer showed a period of extreme depression, the glow was much more active, waxing and waning at intervals of a quarter of an hour through the night, and at other times we have seen great bursts of flame crowning the crater" (Shackleton).

A general characteristic of the coastal walls of South Victoria Land are the "inlets." They are often due to faults; they consist of wide breaches through which the inland ice debouches. Alongside of them and between them are the steep rock walls, likewise a number of ice-free trough-shaped valleys with smooth walls, basins and sills, cwms and lakes, as well as old moraines. The glaciers in these inlets are as much as 50 kilometers wide; this is the case with the Beardmore

Glacier to the south, the largest known valley glacier on earth. Near McMurdo Sound a number of them lie close to each other: Koettlitz, Ferrar, Taylor, and Mackay Glaciers. Some of them serve as outlets of the high ice plateau, others only of local névés; some are now without motion. The first type furnishes a route of access for expeditions to the plateau at the south pole, although their extensive crevassed and ice-fall areas make them difficult. Shackleton and his companions were covered with bruises over and over from continual stumbling on the sharp crevassed ice, and their sledges had to be pushed forward one at a time by short stretches. Scott, too, experienced desperate situations in the ice ruins and crevass labyrinths of the great Beardmore Glacier. Of one locality he writes: "Bad pressure ahead and long waves between us and the land. Blue ice showed on the crests of the waves; very soft snow lay in the hollows. We had to cross the waves in places 30 feet from crest to hollow, and we did it by sitting on the sledge and letting her go. Thus we went down with a rush and our impetus carried us some way up the other side; then followed a fearfully tough drag to rise the next crest. . . . We have patches of hard and soft snow with ice peeping out in places, cracks in all directions, and legs very frequently down." At the foot of the mountain walls in the coastal lowland the special type of piedmont, or foreland, glaciers often occurs; these are not connected with the inland ice and are often produced only by drifted snow masses. Great ice tongues project far into the sea in places, as for example the deeply crevassed Drygalski Glacier Tongue, which is one of the main landmarks on this long stretch of coast, and the sloughed-off, "dead" Nordenskjöld Glacier Tongue.

In the vicinity of McMurdo Sound there are lakes frozen to the bottom that do not thaw for years; for the mean temperature of the warmest month is $-3.9°$ C., though the sun does not set for 120 days, just as at Smith Sound and at Ice Fiord, Spitsbergen. From the white snow blanket the bare black lava rock protrudes; only here and there in rock crevasses and in protected places is there a bit of moss and lichen vegetation, and only animal life persists in its normal abundance. At Cape Adare, although in the same latitude as Hammerfest, Norway, the highest monthly mean does not go beyond the freezing point. In the coldest month both localities, Cape Adare and McMurdo Sound, are alike with a mean temperature of $-26°$. Farther south the cold probably increases considerably. The warmth of the southern winds at McMurdo Sound cannot obscure this fact. This warmth is to be explained as due to the brushing aside of the inversion layers; the stronger the wind, the higher is the temperature in winter. Temperature variation is also large, especially during the winter. Likewise, surprising differences occur within a short distance of each other; a difference of 14° has been recorded three kilometers apart.

Precipitation falls exclusively in the form of snow. Cloudiness and humidity are slight, evaporation great. The south winds for half the time occur in the form of blizzards that may last for days. In addition violent descending winds drop down from the heights of South Victoria Land, diverted into a west-east direction by the inlets. It was to severe and frequent storms of this type that Scott succumbed, whereas Amundsen escaped them farther east on the barrier ice. Calms, however, are as frequent; in the vicinity of Cape Adare, indeed, more frequent. Seasonal shifts in the centers of the atmospheric circulation seem to take place, for the wind velocity at McMurdo Sound is substantially greater in winter than in summer, while at Cape Adare it is just the reverse.

King Edward VII Land

On the eastern side of Ross Sea the only land known is a stretch of coast trending southwest-northeast and lying between latitudes 76° and 77° S. and longitudes 150° and 164° W. It is deeply buried by ice whose surface rises in undulations from the coast. The rock specimens here collected by Amundsen indicate substantially the same Precambrian basement complex that he had found to the south in the ascent to the plateau. This seems to make a structural connection of King Edward VII Land with South Victoria Land more probable than with West Antarctica. What little rock was snow free was covered in places with thick moss.

Ross Sea and the Ross Barrier

In front of the coast of South Victoria Land lies the *senkungsfeld* of Ross Sea. For the greater part of its area it does not descend below the level of the continental shelf. It was discovered by Ross in 1841 and crossed by him to the edge of the barrier ice. In the summer, especially in February, it becomes ice free to a certain extent and thus has afforded access to a number of subsequent expeditions along its western side. In its eastern part the drift ice stays permanently, the rotary current system here flowing to the south, while on the western side it flows to the north. The ice floes are occupied by large flocks of penguins, among them the emperor penguin, likewise by gulls and petrels. In addition to the finback and blue whales, which are numerous here, the ferocious killer whales (*Orca gladiator*) are noteworthy. They are equipped with terrible teeth and hunt in packs, pursuing their prey, including even other species of whales, with cunning. They are strong enough to demolish ice almost a meter thick. Whaling has again been carried on in Ross Sea in recent years; in 1923–1924 the yield was 17,000 barrels of oil. Among the seals the most common is the Weddell seal. On a stretch of ice a hundred meters long there may be between fifty and a hundred. The Ross seal is scarce.

Across the whole of Ross Sea from Ross Island to King Edward VII Land stretches the 750-kilometer-long ice wall (Figs. 101, 102) that constitutes the northern edge of a shelf-ice sheet covering all of Ross Sea south of latitude 78° and hence extending inland over 700

Fig. 101

Fig. 102

Figs. 101 and 102—The Great Ice Barrier, the terminating wall of the Ross Sea shelf ice. Figure 101, a typical stretch seen from Ross Sea. Figure 102, the western end of the barrier at Cape Crozier, Ross Island. Mt. Terror in the right foreground. (Fig. 101 from R. F. Scott's "The Voyage of the 'Discovery,' " Vol. 1, Charles Scribner's Sons, New York, 1905, opp. p. 172; Fig. 102 from "Scott's Last Expedition," Vol. 1, Dodd, Mead, and Co., New York, 1913, opp. p. 54.)

kilometers. This wall-like, abrupt edge rises in general 30 to 50 meters above sea level. The ice sheet itself may reach a thickness of 300 to 400 meters. In its northern part it floats on the water and moves up and down with the tides; even over the sea it grows through the accretion of snow and progresses northwards at the rate of about 500

meters a year. It thrusts off icebergs like an active piedmont glacier, but it is obviously a relict of the Ice Age. Since 1902 the edge seems to have been advancing, whereas prior to that and after 1841 it had been receding, so that in these sixty years the loss through icebergs may have been greater than the replacement through this forward movement. The icebergs derived from it are dazzling white in comparison with the more bluish icebergs derived from glaciers.

The ice of the great glaciers that flows down from the marginal mountains presses into the rather more snowlike ice of the barrier, feeds it, and increases its northward movement. Outstanding among such feeders are the immense Beardmore Glacier, over which Scott advanced, and the Axel Heiberg Glacier, which Amundsen followed. On the way from the marginal sources of supply to the northern end of the barrier the ice constantly melts below and is replaced and renewed by the snow falling above. Viewed as a whole, the barrier is a vast plain; in detail it displays a diversified surface configuration. Smooth stretches alternate with high drifts, snow pillars, and regular undulations; in some places the snow cover is soft, in others it forms a crust as a result of melting or has been blown into hard sastrugi. Where it approaches land crevasses begin to appear. Over this barrier ice lay the routes of the various polar expeditions up to the southern mountain border.

The sub-Antarctic trough of atmospheric depression evidently is deflected southward at Ross Sea, because pressure is at all seasons lower along the ice wall than along the coast of South Victoria Land. As to pressure conditions it is an unstable area like the North European Sea. Over the barrier ice the pressure increases as one goes south; along its northern edge the winds therefore blow from an easterly direction, whereas southwards they become southeasterly. The wind velocity is much less than in McMurdo Sound; calms are very frequent and storms very rare. The temperature therefore remains very low; as compared with McMurdo Sound the annual difference is 8½° C. On the occasion of the lowest recorded temperature at the edge of the ice barrier (−59.9°) it was 18° warmer at McMurdo Sound. In summer this difference disappeared. The temperature then never exceeded the freezing point. The diurnal variability is especially great, amounting on an average to 7° for the coldest month. The reason for this lies in the steep temperature gradient that obtains between the ice barrier edge and the water in front of it, which especially in winter becomes a veritable thermal avalanche.

In the eastern part of the ice wall there is an embayment related to a local elevation in the ice. As a result this bay becomes a focus for animal life. Murray, the biologist of the Shackleton expedition, describes it in the following terms. "This bay, which we afterwards referred to by the appropriate name of the Bay of Whales, was teeming

with all the familiar kinds of Antarctic life. Hundreds of whales, killers, finners, and humpbacks, were rising and blowing all around. On the ice groups of Weddell seals were basking in the midnight sunshine. Emperor penguins were standing about or tobogganing in unconcerned parties. Skua gulls were flying heavily, or sitting drowsily on the ice. Only the Adélie penguin (busy nesting elsewhere) and the rarer kinds of seal were absent." This Bay of Whales afforded Amundsen easy access to the barrier ice and a protected position for his winter station, Framheim, whence he reached the pole.

The Northern Coast of East Antarctica

The inland ice back of South Victoria Land is bounded on the north by the long outer coast of East Antarctica. From the vicinity of the Balleny Islands to Coats Land this coast extends through 180° of longitude in practically the same latitude, lying mainly along the Antarctic Circle; it gradually recedes, however, toward higher latitudes from the 50th meridian of east longitude to Coats Land. In contrast to South Victoria Land only disconnected stretches and points of this coast are known. That is due to the dense girdle of ice that accompanies this east-west trending coast. Many expeditions that made advances in this region did not even see the coast. Von Drygalski's was the first to set foot on the mainland of the continent itself, and Mawson's the first to survey longer stretches; but even on this, so far the most successful expedition, it was only possible to survey 6° in longitude of coast from the ship, while 27° were surveyed on sledging trips. At the extreme eastern end there first comes, between Robertson Bay, with its 250-meter-high Cape Adare, and Cape North, a stretch of coast that is paralleled by the Admiralty Range and that with its mountains, its debouching Dugdale Glacier, and its reëntrant Smith Inlet is not unlike a part of the adjoining north-south coast of South Victoria Land.

Proceeding westward there follows after a gap Oates Land, then King George V Land, Adélie Land, and, in longitude 135° E., Wilkes Land (in Mawson's restricted sense), then a long stretch with old landfalls only to Knox Land, then Queen Mary Land, and Kaiser Wilhelm II Land with the Gaussberg in longitude 90° E. To the west of this a slightly inward curve of the coast is probable; then follow Kemp and Enderby Lands in longitudes 60° and 50° E. respectively, and finally, not until longitude 15° W. is reached, Coats Land. Between Enderby and Coats Lands the coast probably lies not far south of the farthest points reached in the pack ice by the expeditions of Cook, Bellingshausen, Biscoe, Ross, and Moore.

The coastal shelf is narrow; in places its outer edge is higher than the shelf farther back. In front of several segments of the coast lie

great bodies of shelf ice, surrounded by jammed masses of pack ice, for example the West Ice near Gaussberg and, off Queen Mary Land, the Shackleton Shelf which, as the Termination Ice Tongue, projects outward to beyond latitude 64°.

The inland ice, descending from the high plateau at the pole, slopes down from an elevation of about 1000 meters for the last 30 to 50 kilometers, often in the form of ice cascades and much crevassed,

FIG. 103—West side of the Gaussberg, a volcano projecting from the inland ice on the edge of the continent in East Antarctica. (From report of German Antarctic Expedition, 1901–1903, Vol. 1, No. 4, Berlin, 1921, Pl. 18.)

and ends in an abrupt vertical cliff 40 to 50 meters high. In the marginal area coastal rocks rise above it as nunataks or lie offshore as islands. The whole land mass consists in the main of a basement complex of gneisses and granites in part covered by sandstone strata (Beacon sandstone) and in places interrupted by volcanic rock. In longitude 150° E. a long stretch of imposing, high cliffs consist of columnar dolerite. Gaussberg (Fig. 103) is a Tertiary volcanic cone that projects 371 meters above the sea at the edge of the inland ice. Its lava consists of leucite basalt, which places it also, like the volcanoes of the Ross Sea area, in the group of volcanoes of the Atlantic type. It is covered with moraines up to its summit. Rock terraces interrupt its slopes. That there may be other volcanic hills in the vicinity under the ice von Drygalski believes is probable. He considers it certain, however, that there is a volcanic submarine ridge between this volcanic region at the edge of the old crystalline continent and the distant

volcanic area of Kerguelen. This Gaussberg-Kerguelen Ridge extends obliquely from the continent north-northwest for 2200 kilometers; at several points along it recent volcanic peaks or rocks and rock fragments have been determined. It therefore represents an immense zone of disturbance within the domain of the continental oldland. At the same time this rise has oceanographical significance because it deflects the warmer water of the Indian Ocean through the Kerguelen Trough to the continental shelf of East Antarctica.

The northern margin of East Antarctica is characterized by the most violent and persistent air movements of all land areas on earth. For days and even for weeks the wind varies only between storm and hurricane velocity and is often accompanied by so severe blizzards that it seems as if the air were completely filled with snow. How a vessel in the coastal ice may literally become the plaything of these storms was experienced by the *Gauss*. "The wind had risen to the intensity of a snowstorm which blotted out everything. We fought against it under full steam, now on a southern tack, now on a northern, without being able to accomplish anything. Certain it is that we drifted much in the storm, like the ice about us, that in the form of icebergs and floes appeared hither and yonder in the fog where it had not been before and thus only revealed the general motion to us. The low visibility brought about countless optical illusions. Low floes which pressed in on us seemed magnified into immense on-rushing icebergs that threatened to bury the ship and all of us the next instant under their weight, only to disappear in the mist when they actually reached us or else drift by as small floes. But among them there were some real icebergs of great size that it was necessary to avoid. . . . Always it was the same picture of complete impotence, of a struggle with the elements which surrounded us in overpowering might" (von Drygalski).

At the *Gauss* station these storms blow from the east, in Adélie Land from the south-southeast so steadily that one can set one's course by them. Here Mawson lived practically through two years of constant storm winds with a mean annual velocity of 23 meters per second, daily means of 40 meters per second, and some absolute velocities of 90 meters per second, i. e. almost twice the hitherto known velocity of hurricanes. To be sure Mawson's station seems to have been under the influence of special and locally limited conditions. The wind-tossed coastal water froze into fantastic forms—a frothy sea of ice. Farther out, however, the sea was kept free of ice by the wind, even in winter. The southern sides of rocks were scoured smooth, the lee sides were rough. Not infrequently objects weighing hundreds of pounds and the men themselves were swept through the air for yards. Walking was possible only with crampons and not vertically but only by holding the upper part of the body nearly horizontal in

the teeth of the wind. In every respect life had to be adapted to the force of the wind. "The contrast was so severe when the racking gusts of an abating wind suddenly gave way to intense, eerie silence, that the habitual droning of many weeks would still reverberate in the ears. At night one would involuntarily wake up if the wind died away, and be loth to sleep 'for the hunger of a sound.' In the open air the stillness conveyed to the brain an impression of audibility, interpreted as a vibratory murmur" (Mawson).

The mean annual temperature in Adélie Land (on the Antarctic Circle) had the same low figure as McMurdo Sound; at the Gaussberg this value was 6° higher. At this station namely the strong winds have less of a southern component than in Adélie Land; they therefore have a more pronounced cyclonic character, with all its attributes of warmth and moisture. For this reason the calmest weather prevailed during the months in which the depression trough withdrew northwards. The summer thaw is very slight even here on the Antarctic Circle, and the *Gauss* was liberated from the ice field that held it fast less as a result of melting than through the motion of and thermal changes in the sea. The disappearance of snow is thus brought about less through warmth than through the sweeping and evaporating force of the wind. As a result of their scouring effect the winds create a special type of ice, the blue ice. Rock surfaces that are subjected to these winds lack all vegetation and detritus. Only in protected places and where there is some melt-water are mosses and lichens, in places abundant, to be found. At the Gauss station no algae grow along the coast. Even the seals in Adélie Land were not able to stay on land during the violent winds because they would have been blown off.

Coats, Caird, and Luitpold Lands

A continuous coast, first discovered by Bruce and whose outline was extended by Filchner and Shackleton, runs from latitude 72½° and longitude 17° W. southwestwards to about latitude 78°, where, as in Ross Sea, an east-west ice wall abuts on it. The names of the land are in order: Coats Land, Caird Land, and Luitpold Land. Here the inland ice, which descends in undulations and terraces, ends in great ice cliffs whose height varies between a few meters and nearly a hundred meters; in places it is deeply broken up and crevassed. To land on it is difficult. Filchner was able to do so under great hardship but not able to establish a secure station. He saw nunataks on the Luitpold Land coast but could reach none of them. Here the edge of the ice still rests on the bottom of the sea. Inland the surface of the ice rises to elevations of several hundred to a thousand meters. At Luitpold Land the underlying land seems to show plateau character. This, together with the rock specimens dredged by Bruce, seems to

indicate connection with East Antarctica rather than with West Antarctica. The winds also, as generally on the eastern side of Weddell Sea, are still predominantly from the east, and the blue-ice type of iceberg occurs.

Weddell Sea and the Weddell Shelf Ice

Between what seems to be the outermost corner of East Antarctica and the peninsula of West Antarctica there lies a deep embayment of the ocean whose name is derived from the sealer Weddell. He penetrated to latitude 74° as long ago as 1823, a southing that was only repeated by Bruce in 1904. To the south the sea is covered with an ice sheet, the Weddell, or Filchner, Shelf Ice (Fig. 9, p. 33). Filchner found its margin to be loosened by immense series of crevasses and witnessed the tremendous spectacle of a piece larger than the Lake of Constance breaking off as a result of a spring tide. In spite of our meager knowledge this ice sheet is certainly to be classed with the Ross barrier ice. In front of it there extends a shallow sea 600 to 700 meters deep which is set off from the deep sea by a threshold rising to within 400 meters of the surface. Within this threshold lies very cold bottom water with a temperature of $-1.9°$ C. In front of it the water in corresponding depths is 2° warmer. The cold, salter water of the deep parts of Weddell Sea is caused by descent over this threshold. These deep parts in the north attain depths of 4000 and even 5000 meters and east of the South Sandwich Islands are connected northwestwards with the Argentine Basin and its great depths, found by the *Meteor* of the recent German Atlantic Expedition to exceed 8000 meters.

According to the observations of the *Gauss* expedition and the researches of W. Brennecke the influence of the Antarctic on the circulation of South Atlantic waters extends as far north as the tropics. Under the surface currents lies a colder, less saline body of water moving northward; in the layer from 1500 to 3000 meters below the surface there is south-flowing warmer water; and finally below this there is cold bottom water which is formed through the mixture of Antarctic water with tropical water. On the surface of Weddell Sea there is a tendency to a rotary current. The drift of Filchner's and Shackleton's vessels took place in its western part in conformity with the clearly developed and climatically influential Weddell Sea barometric minimum studied by Mossman and the writer. At the western side of this sea the temperature of the air, as a result of its southern origin, accordingly remains 1° to 3° C. less than that of the water under it even in summer. The ice is here pushed forward vigorously into the South Atlantic, whereas west of the 60th meridian of west longitude its occurrence in the ocean is far rarer. Obliquely in the way of this outward-pressing ice stands the peninsula of West Ant-

arctica like a breakwater, and this slightly different situation from that at Ross Sea seems to me to be the reason for the unfavorable ice conditions of the western part of Weddell Sea as compared with those of the western part of Ross Sea, whose wind and current system is otherwise fundamentally the same. In Weddell Sea true pack ice therefore occurs, particularly in the west. The southern winds bring low temperatures and clear weather. Nevertheless the minimum temperatures do not sink very low; on the two drifts mentioned −37° and −39° C. were observed. Temperature inversion, according to the aërological observations made on Filchner's drift, is very large. Seals and birds, among the latter the emperor penguin, dwell on the ice floes; the *Scotia* here collected 74 species of birds.

The Peninsula of West Antarctica

The earliest Antarctic exploration took place in West Antarctica; it began during the age of discovery. In the nineteenth century it was mainly carried on by whalers. However, the unveiling and delimitation of the complicated outline of this region is chiefly due to the work of recent expeditions, among which the Swedish Antarctic Expedition especially has given us an insight into the geological structure. At its tapering end in latitude 63° the peninsula of West Antarctica bears the name Louis Philippe Land. On its eastern side there then follows King Oscar Land and on the western side Danco, Graham, Loubet, Fallières, and Charcot Lands. Far off on the ninetieth meridian lies Peter I Island; near Charcot Land lies Alexander I Island; farther north the coast is accompanied by Adelaide Island, the Biscoe and Palmer archipelagoes, and finally, separated from the mainland by the wide Bransfield Strait, the South Shetland Islands, which are continued to the east-northeast by a series of sub-Antarctic islands. On the Weddell Sea side of the peninsula two large islands lie off shore in the north, Joinville

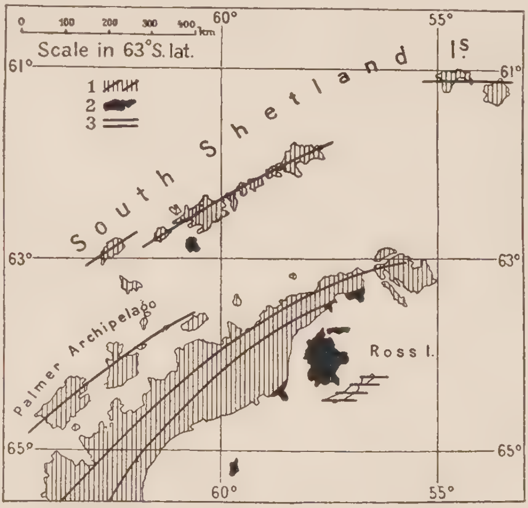


FIG. 104—Structural sketch map of the peninsula of West Antarctica. Mean scale about 1:8,000,000. 1, folded zone with Andean eruptives; 2, zone of basaltic lavas and tuffs; 3, zone of horizontal sedimentaries.

Island and James Ross Island, and farther to the south a number of smaller ones.

The peninsula, together with the western island chains, represents a wild ice-covered mountain range with crests over 2000 meters high, the highest peak, in the Palmer Archipelago, being 2870 meters in elevation, and with deep, often trough-shaped valleys. The mountains decrease in elevation towards the north. It is a folded mountain range which is structurally related to the Andes of South America but which, to a greater extent than they, consists of batholithic rocks. The eruptive rocks are present to a greater extent than the folded

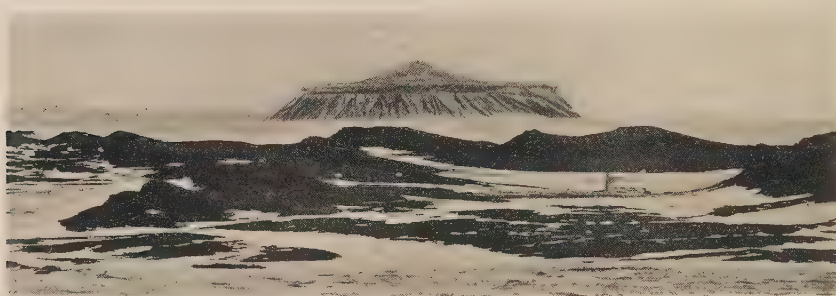


FIG. 105—Cockburn Island, on the east side of the peninsula of West Antarctica. Under a sheet of hard volcanic tuff lie Cretaceous sandstones with steep slopes. The island is seen beyond Seymour Island, of which the Tertiary sandstones are visible in the foreground. (From Wiss. Ergeb. der schwed. Südpolar Expedition, 1901–1903, Vol. 1, No. 1, Stockholm, 1911, Pl. 2.)

metamorphic slates and the slightly folded Jurassic strata, the granite-diorite-gabbro series predominating in the central range, as in the whole Andean system. The major valleys and the outline of the coast run parallel to the direction of folding, especially the western island chains and the channels, which are only sunken valleys, as is likewise the case with the 1500-meter-deep fault basin of Bransfield Strait.

On the eastern side the islands that lie in front of the folded ranges are remnants of a Cretaceous and Tertiary sandstone and conglomerate plateau, for the most part overlain by tuffs and basalt sheets and interrupted by dikes (Fig. 105). Here Mt. Haddington rises to 2000 meters. This mountain, and indeed all of James Ross Island on which it lies, seems once to have been a great bedded volcano. Neither recent nor active volcanoes occur. This eastern sedimentary and volcanic zone has evidently only been broken up into islands by denudational agencies. Plateaus, bastions, terraces, and steep dark cliffs are the characteristic forms. Another, younger volcanic area lies north of the Bransfield trough. Here, on Deception Island, the crater form is still intact, and fumaroles and hot springs give evidence of recent activity. The downdropping of the strait may be related to this volcanic activity.

In these, its main belts, the western folded range, with its longi-

tudinal channels and its dissected fiordlike coast, and the eastern tabular zone, West Antarctica is the reflected image of southern South America. What parts of the sub-Antarctic islands and of the ocean floor are the connecting links between these two elements is not yet clarified, however.

In the western mountain belt glaciation has its maximum development. The range, to be sure, carries no real inland ice—for this its size and shape are little suited; however, it is so intensely glaciated that even steep peaks are completely blanketed and the ice gathers on the western coast in great foreland glaciers, which thrust off tabular

FIG. 106—Snow Hill Island, on the east side of the peninsula of West Antarctica. Ice-free area in the zone of horizontal sedimentaries. This was the winter station of the Swedish Antarctic Expedition of 1901–1903. (From Pl. 16, Fig. 2, same source as Fig. 105.)

icebergs. The glaciation of Spitsbergen should under ordinary circumstances be directly comparable. In the Palmer Archipelago, however, the snow line descends down to sea level. Small islands are completely covered by ice domes. The highest elevations of the islands protrude from the ice cap. In the straits icebergs drift past by the hundred. Even along the southern coast of Belgica Sea (which extends between Peter I Island and the peninsula of West Antarctica) there are many; Charcot in a few days here saw thousands of tabular icebergs. In the eastern level zone of the peninsula there are large ice-free areas, because the severe winter storms of Weddell Sea blow away the not very abundant snow (Fig. 106). On the other hand in this zone, between latitudes 65° and 66°, lies the Nordenskjöld Shelf Ice. In the past the upper limit of glaciation lay 300 meters higher. Gerlache Channel on the western side, between the Palmer Archipelago and the mainland of the peninsula, may be interpreted as the bed of an ice stream.

Climatically, too, the western and eastern sides of the peninsula are contrasted. According to the investigations of the writer this is due to the separation of the lows in the Belgica and Weddell Seas respectively by a West Antarctic high-pressure wedge. The low-pressure area in the Weddell Sea is more or less permanent, whereas that in Belgica Sea tends to disappear in winter. This is the reason

for the monsoonal character of the wind on the Belgica Sea side and for its predominant southwest direction on the Weddell Sea side. The low-pressure area here powerfully draws the air from the higher latitudes, and Snow Hill in latitude 64⅓° has the same mean annual temperature as the *Gauss* station as a result of these severe southwest storms. But the atmospheric situation along the narrow high-pressure wedge is in a state of unstable equilibrium, and thus abrupt changes and irregularities in all climatic elements are the second characteristic feature of the region. The wind of the moment is everything; the seasons lose their importance. August of one year at Snow Hill reached the absolute minimum of temperature (−41.4° C.), August of another year the maximum (9.3° C.). The mean variability in many months amounts to as much as 4° to 5°.

By contrast, the western side has much less extreme conditions. Here the mean annual temperature is 8° higher than in corresponding latitudes on the eastern side, and the January mean rises above the freezing point because the northeastern winds of the Belgica Sea low-pressure area, which predominate in summer and are not lacking in winter, are warm winds. In all months the temperature here occasionally rises above 0°C. But the short-period fluctuations are great here, too. The climate is maritime in character, the weather changeable and mild. The relative humidity, amounting to 80–88 per cent every month, is similar to that of Cape Horn. Precipitation is frequent and often in the form of rain. Even at the end of March there were rains that came down in streams, "just as in Brest or Cherbourg" (Charcot).

In other respects there is marked parallelism between the east and west coasts with regard to the broader aspects of weather conditions. When pressure is high in the west it is especially low in the east and vice versa. While therefore in the former region cold weather sets in when the air is calm, the same cold is produced in the latter area by southwest storm winds; and whereas in the former high temperatures are produced through the northeast storms of a low-pressure situation, they develop in the latter area when storms are lacking. These reciprocal relations, according to my investigations, extend over Drake Strait to South America, especially on the Pacific side.

Vegetation is relatively more abundant on the milder west side of the peninsula of West Antarctica. This is the optimum habitat of the continent. The rocks, too, are here more favorable to vegetation than the sands and tuffs of the east coast. Tundras and grasslands are the dominant formations. Especially on northern slopes there are extensive moss colonies that generally consist of a number of species, and a lichen cover occurs up to an elevation of 300 meters. Both mosses and lichens are represented by about 50 species each. The snow is discolored by algae. The two existing phanerogams,

however, are of no consequence in the landscape. In addition to a few insects and spider-like animals there are seals and birds, especially crab-eaters and Weddell seals and penguins. On these animals and on fishes twenty men of Nordenskjöld's expedition lived for a winter after the foundering of the *Antarctic*.

The Islands of West Antarctica

To the north of the peninsula of West Antarctica a series of island groups is arranged in the form of a great arc that extends from the South Shetlands by way of the South Orkneys, the South Sandwich Islands, and South Georgia to Tierra del Fuego, so that it is natural to compare it with the Antillean arc. Formerly, indeed, it was taken for granted that South America and West Antarctica were connected through this arc. But as a result of recent research this assumption is to be questioned. It is possible that South Georgia and the South Orkneys are the remains of an old continental mass that is related to the Brazilian oldland.

Whereas the Palmer Archipelago still forms an integral part, structurally and in general aspect, of the peninsula of West Antarctica, the South Shetland Islands, separated by the fault basin of Bransfield Strait, are a relatively independent unit. But in character they are hardly removed from extreme polar conditions; indeed, they stand at the other end of the great contrast that exists between them and the southern end of South America only 7° of latitude farther north across Drake Strait—a contrast which was admirably characterized by Darwin. Farther out then come those island groups that, because of their milder winters, their lower temperature range, their greater amount of ice-free surfaces, their abundant precipitation, and the presence of a perceptible plant cover are set off as sub-Antarctic, namely the South Orkneys, the South Sandwich Islands, and South Georgia. The Falkland Islands, to be sure, are fairly similar in character; but in position, configuration, and economic life they are so closely related to South America that they are usually assigned to that continent.

The South Shetlands

Between latitudes 61° and 63° the South Shetlands, together with Elephant and Clarence Islands that lie somewhat apart, constitute a chain over 500 kilometers long. They are a wild, mountainous land with sharp peaks surrounded or covered by ice. The rocks examined on the occasion of the infrequent visits to the islands proved to be mainly andesitic lavas; these, again, have their counterpart in the Andes. On Elephant Island, however, the rocks are mainly phyllites.

Deception Island is a beautiful breached crater into which the sea has entered. Its ice is being undermined by volcanic gases, steam,

and hot springs. Mosses and lichens in places occur in sufficient quantity to form carpets, and insects thrive in these; grass is lacking. There are two penguin rookeries of 50,000 birds each. Its excellent harbor served once after 1820, as a base for American sealers, and recently it has become a center for Norwegian and Chilean whalers. Even in 1908 Charcot found 200 persons living here. In 1923–1924 the waters around these islands yielded about 200,000 barrels of whale oil.

The South Orkneys

Five hundred kilometers distant from the peninsula of West Antarctica the South Orkneys rise above the sea in latitude 61°. Of the two main islands Laurie Island, the only one investigated, consists of hard Silurian graywacke which is steeply folded but whose strike is northwest, i. e. it does not continue the direction of the peninsula and evidently represents an older mountain folding. The mountain ranges have been submerged to such an extent that only their highest peaks project from the sea. Lying on the northern side of the low-pressure trough the group is swept by west and northwest winds. Four-fifths of the year the sky is completely overcast; in this respect the group constitutes the Antarctic counterpart of Jan Mayen. Precipitation also is ample. The temperature, as compared with Snow Hill, is relatively high (annual mean, –4.6° C.). However, it varies greatly both diurnally and annually, i. e. polar influences break in often and suddenly. The temperature is dependent less on local winds than on their ultimate origin, namely the general weather situation in West Antarctica and Drake Strait. The January mean barely exceeds the freezing point. Therefore the cold desert and tundra of the Antarctic still reign here, leaving opportunity only for the development of mosses and lichens.

The South Sandwich Islands

About 1000 kilometers farther east lies the arcuate chain of the South Sandwich Islands between latitudes 55° and 60° S. Although discovered by Cook they have been little explored. So far as known they are all small volcanic islands, from some of which steam is still emanating. They are conical in form and rise to elevations of only a few hundred meters. Several of them carry ice caps. Penguins, especially the emperor penguin, live here in great numbers.

South Georgia

Northwest of the Sandwich group, between latitudes 54° and 55°, lies South Georgia, 4000 square kilometers in size. In 1882 to 1883 it was occupied by one of the German polar stations. Like the South

Orkneys, the island trends southeast-northwest and is crossed in the same direction by a folded mountain range, with folds overthrust to the north and with rocks mainly of Mesozoic but also of Paleozoic age. Magmatic rocks and volcanic tuffs also occur. Over the deep glacier-filled valleys and the generally steep and sinuous fiord coast rise rugged snow-capped peaks to elevations over 2000 meters. Glaciation was once more extensive than now. The present snow line lies at an altitude of about 500 and 600 meters. The mountains are frequently blanketed in fog. The proximity of Weddell Sea, with its tendency to project cold weather northwards, produces low temperatures (annual mean, 2.4° C.) for an island that lies in the latitude of southern England, and the low pressure nucleus of Weddell Sea exerts the same influence as in the case of the South Orkneys, so that the temperature curves of both always parallel each other. Precipitation is abundant, 1350 millimeters falling even on the protected northeastern side; no month had less than 20 millimeters, many months had more than 200 millimeters. As the result of föhn effect the snow cover is less on the northeastern side. Here lies Cumberland Bay with its active whaling station.

In the lower-lying lands plant growth is dense, especially as represented by the shocks of tussock grass higher than a man. Sheep breeding does not seem to be without prospects of success. However, there are only 19 flowering plants and ferns as contrasted with nearly 200 species of mosses and lichens. These last constitute the tundra, especially uniform in the interior. *Macrocystis* kelp densely girdles the shore and dampens surf action. Fish abound in it; and considerable fishing is carried on. Albatrosses, gulls, and penguins breed on the islands and reefs, sea elephants lie on the beach; on the other hand, the typical seals of Antarctic waters are missing. Animal and plant life concentrates along the sea and decreases as one goes inland and upward, until above an elevation of 700 meters all life has ceased. The existing plant and animal species show close relationship with South America.

For more than a hundred years the island has served as headquarters for sealers. Now there are a number of whaling stations here, among them Grytviken on Cumberland Bay, the largest station in the southern hemisphere. It was established at the beginning of the present century after the renaissance of Antarctic exploration. In number of inhabitants and buildings it resembles a small village. The coast is even marked with lighthouses in places, and there is permanent communication with Buenos Aires. In 1923–1924 South Georgia produced more than 200,000 barrels of whale oil. The whale fishery is here carried on by one Argentine and several Norwegian and British companies. The present administration is endeavoring by protective measures to curb the former ruinous exploitation.

The Sub-Antarctic Islands of the Indian Ocean

In the southern part of the Indian Ocean there lie scattered a number of volcanic islands and archipelagoes, among which Kerguelen is the chief. This island is equally distant from South Africa and southwestern Australia. A little to the south of it lies the Heard group, to the north of it St. Paul and New Amsterdam Islands.

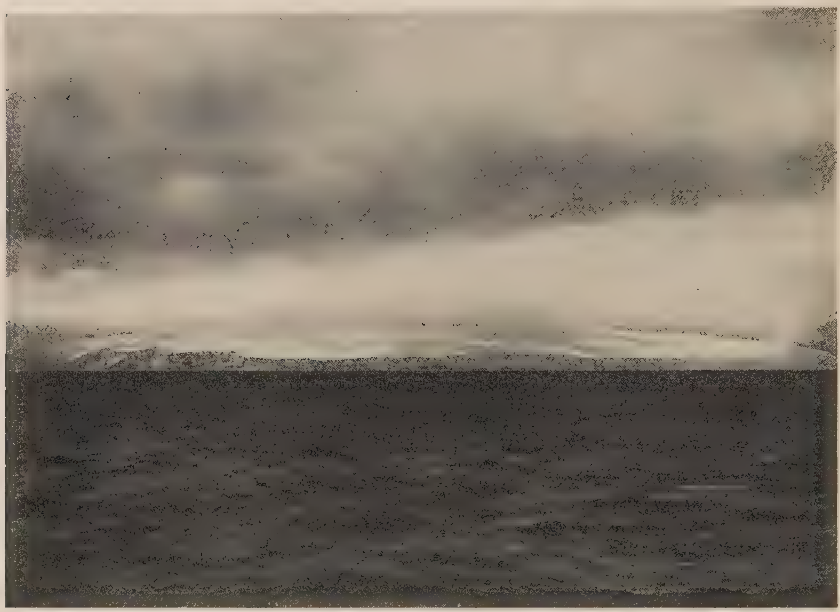


Fig. 107—Bouvet Island. Ice cap breaking off abruptly to the sea. (From Wiss. Ergeb. der Deutschen Tiefsee-Expedition auf der 'Valdivia,' 1898-1899, Vol. 10, No. 1, Jena, 1905, Pl. 8.)

Westward, about half the distance to South Africa, come the Crozet and Marion groups and then, as a last outpost, Bouvet Island, although this strictly belongs to the Atlantic region.

Bouvet Island

Lying in the same latitude as South Georgia but far from it, in longitude 3½° E., Bouvet Island (Fig. 107) rises lonely and abruptly from great depths to an elevation of 900 meters above sea level. Discovered as long ago as 1739 this small island pillar had been lost until the German deep sea expedition of the *Valdivia* found it again in 1898. The influence of Weddell Sea makes itself felt in the fact that this island is completely covered with ice and snow (in the same latitude as Heligoland!). In spite of its ice cover its shape as well as the basalt and tuff specimens dredged near by show that it is a volcanic cone.

The Marion and Crozet Groups

The small islands between latitudes 46° and 47° lying southeast of the Cape of Good Hope were all discovered in 1772 by French vessels under Marion Dufresne and one of his officers, Crozet, and were at that time still thought to be the northern ends of the mythical southern continent. Our first knowledge of them and most of their names

FIG. 108—Topography of Kerguelen Island. In the foreground, *roches moutonnées;* in the middle distance and background, plateau forms. (From Vol. 2, Part I, No. 1, Pl. 1, same source as Fig. 107.)

are due to Cook, however. The present names vary. The western group is called Prince Edward or Marion Islands, the eastern group Crozet Islands. The largest of the latter group is only 25 kilometers long. Both groups rise steeply from a submarine plateau that divides the Atlantic from the Indian Ocean and rises to within 3000 meters of the surface. Both are rocky and of recent volcanic origin. Lava streams and crater cones were found on Possession Island by the *Gauss* expedition. The relief varies between 100 and 1000 meters in elevation and is partly conical in form.

The flora is closely related to that of Kerguelen, whereas the fauna differs considerably, for example by the fact that there are three endemic bird species. A dozen flowering plants were found by the *Gauss* expedition. Kelp borders the shore. Grassy areas, swamps, and moors occur inland and are inhabited by sea elephants and penguins. Pigs and rabbits were also introduced by American sealers in the nineteenth century. The climate is controlled by the fact that

the islands are completely in the west-wind belt. All expeditions mention the fog blanket. The temperature during the days of midsummer on which the *Gauss* stopped there varied between 4° and 7½° C. The snow limit seems not to descend much below 1000 meters. France has recently formally taken possession of the islands.

The Kerguelen Group

Two thousand kilometers north of the Antarctic Continent, Kerguelen lies between the parallels of 48½° and 50° south latitude and the meridians of 68½° and 70½° east longitude, being 5000 square kilometers in size. It was discovered in 1772. It consists of a triangular main island with hundreds of minor islands and skerries and constitutes a volcanic tableland composed mainly of basalts and tuffs, mostly 500–1000 meters high, but dissected to a surprising degree by radial glacier-formed valleys and inlets, so that the tableland is divided into individual plateaus and even ridges and peaks. Mountains of tabular, terraced, and conical form dominate the landscape (Fig. 108), and lakes are abundantly scattered throughout. The west coast is bordered by an ice-covered ridge about 1000 meters high which ends in the south in a crater cone, Mt. Ross, almost 2000 meters high. In the south the ridge is broader and carries a continuous névé cover. The elevation of the snow limit is placed at 600 meters by Werth, i. e. considerably lower than in Greenland. Glacier tongues in places reach the sea; on the whole, however, glaciation is incomplete. In former times the ice covered nearly all of the land.

The limit of drift ice in these waters bends far to the south. The climate of Kerguelen is therefore markedly oceanic, to an extent that is hardly the case elsewhere in these latitudes. Lying directly athwart the path of the lows, the group has thoroughly unstable weather. The temperature range, however, is truly oceanic in its smallness, the annual range amounting only to 6½° C. with a mean annual temperature of 3½°. It is a characteristic of the islands that the sky is always partly overcast. The precipitation probability is very high—over 80 per cent—but the amount is generally small. Snowfall occurs at all times, even in summer. "Hardly anywhere in the temperate and tropical zones will it be possible to find an equivalent of what the observers on this lonely, isolated island of the Indian Ocean had to endure as 'Kerguelen weather,' cold, fog, and dampness alternating with rain storms and snow squalls throughout the year" (Meinardus). The wind velocity, with its annual mean of 8.6 meters a second, exceeds even stormy Snow Hill, because the calms of the Antarctic practically do not occur. On the surfaces that are swept by the westerly storms only few plants grow, but in areas protected from the wind there are connected plant covers—oases in

this wind desert in the form of tundra and heath. Sheep raising seems possible here.

The plants seek to protect themselves from desiccation by the development of cushions, so that cushion plants, primarily *Azorella Selago*, are characteristic of the landscape where it is not bare. Swamp and water plants are frequent as well as mosses, lichens, fungi, and algae. Of flowering plants there are only 20 species. Insects here have no wings or only stunted wings. The higher animal life is represented by penguins, sea elephants, and sea leopards. The sea elephants were hunted intermittently during the nineteenth century and have again been hunted for some time; in 1920–1921 the oil yield was 2000 tons. Politically the group is claimed by France on the basis of its right of discovery.

The Heard Group

From the same submarine bank as Kerguelen and 550 kilometers southeast of it rises a small group, likewise volcanic, consisting of Heard Island (350 square kilometers in size) and the McDonald Islands, so named respectively after their discoverers, who came upon them in the fifties of the last century. The McDonald Islands are steep, unapproachable cliffs 200 meters high; on Heard Island a landing at least can be made. It is dominated by Mt. Kaiser Wilhelm, whose elevation is estimated to be 1800 meters. It carries an ice cap from which glaciers descend to the sea without, however, producing icebergs. On its moraines and gravels grow *Azorella* cushions and between them Kerguelen cabbage (*Pringlea antiscorbutica*), whereas mosses and lichens are less frequent. The meager vegetation harbors some flies and insects. On the shores kelp is found. Water pools are the haunts of the sea elephants. Birds fly in flocks about the shores. The whole picture of life is similar to that of Kerguelen, only poorer. The climate, as evidenced by the heavy glaciation, is substantially more polar; eastern winds are more frequent, although the west winds still predominate. According to the indirect deduction of Meinardus the mean temperature in February is less than 3° C., the annual mean 0°—an extremely low value for the latitude of Liverpool. Here, too, for years there was a whaling station.

St. Paul and New Amsterdam Islands

These two northernmost islands differ in various respects from the sub-Antarctic islands proper of the Indian Ocean. Lying between latitudes 37° and 39° S., they were discovered hundreds of years earlier and have been visited by many expeditions as well as sealers and fishers. A substantially milder climate, a more luxuriant plant growth—on New Amsterdam there are 33 species of flowering plants—

at times also permanent human inhabitants raising animals that range from chickens to cattle and growing potatoes and even cereals—all this removes them far from the others, whereas their recent volcanic character, their still predominantly grass and shrub type of vegetation, and their distance from the continents relate these islands to the sub-Antarctic groups.

The Sub-Antarctic Groups Near New Zealand

Around the southern end of New Zealand and connected with it by shallow depths of the sea are grouped the Bounty and Antipodes Islands, Snare's Island, the Auckland Islands, Campbell Island, and Macquarie Island with its adjoining islets. Our knowledge of their character rests mainly on the investigations of an Australian expedition of 1907. They are mostly very small, the largest of the Auckland Islands as well as Macquarie Island being less than 40 kilometers long. Many of them consist of granites, gneisses, diabases, and gabbros; but recent volcanic lavas and tuffs form part of the rock structure, this being the case with Campbell Island and the Antipodes and Auckland Islands. In the larger islands undulating uplands rise several hundred meters: in Macquarie over 400, in the Auckland Islands over 600. During the Ice Age they were in part glaciated, at present they are no longer. The coasts are generally steep, high, and jagged, especially on the windward western and southern sides. They have the stormy, cool, temperate, and moist climate of the west-wind belt, especially so Macquarie Island. In November the temperature can here still occasionally drop to the freezing point.

Even in the short periods of sunshine the plant cover is constantly damp and dripping. It is considerably more luxuriant than on the sub-Antarctic island groups of the Indian Ocean. Taken together, the islands have as many as 200 species of flowering plants, most of them occurring on the Auckland Islands. But the plant formations are graded. The southernmost islands, especially Macquarie, have neither trees nor bushes, only tussock meadows and *Azorella* cushions or shrubs three meters high. The more northerly islands on the other hand, like the Aucklands and Snare's Island, have trees and tree ferns, although, to be sure, in their development and shape they reveal their hard struggle against the wind. Some also, like the small Bounty Islands, are almost bare.

The shores abound in penguins, albatrosses, sea elephants, and sea leopards. Sheep and hogs also occur on some of the islands. The fur seals that once occurred in vast numbers on Macquarie Island were nearly exterminated soon after its discovery. From a species of penguin that here occurs in the hundred thousands oil is produced. The island is a veritable place of refuge for sea elephants; although

elsewhere they have been largely destroyed, there are still enough here to be hunted. An adult sea elephant (Fig. 99) may have a layer of fat up to 20 centimeters in thickness and yield 500 to 900 kilograms of oil. The "elephant season" lasts about three months; before it ends the "penguin season" begins.

Of the life on Macquarie Island Mawson draws the following picture: "Thick tussock-grass matted the steep hillsides, and the rocky shores, between the tide-marks as well as in the depths below, sprouted with a profuse growth of brown kelp. Leaping out of the water in scores around us were penguins of several varieties, in their actions reminding us of nothing so much as shoals of fish chased by sharks. Penguins were in thousands on the uprising cliffs, and from rookeries near and far came an incessant din. At intervals along the shore sea elephants disported their ungainly masses in the sunlight. Circling above us in anxious haste, sea-birds of many varieties gave warning of our near approach to their nests. It was the invasion by man of an exquisite scene of primitive nature."

BIBLIOGRAPHY

No reference is here made to the older literature of the subject, which consists almost exclusively of descriptions of travel and accounts of voyages; this literature is summarized in or easily accessible through general histories of exploration, in especially complete form, for example, in Hellwald's book listed below under the Arctic. Only exceptionally have publications issued prior to the "international polar year" (1882–1883) been included. Of each of the voluminous scientific reports of expeditions, which often consist of dozens of memoirs usually of fundamental importance by a number of different authors, only the general title has been given. Even with regard to the important series *Meddelelser om Grönland* a summary reference must suffice, as it is hardly possible to make a selection among the hundreds of monographs all directly bearing on the regional geography of that area. Articles in periodicals have been included only in a few special cases. A number of Russian works are mentioned, although I was not able to use them.

The Polar Regions As a Whole

History of Exploration and General Descriptions

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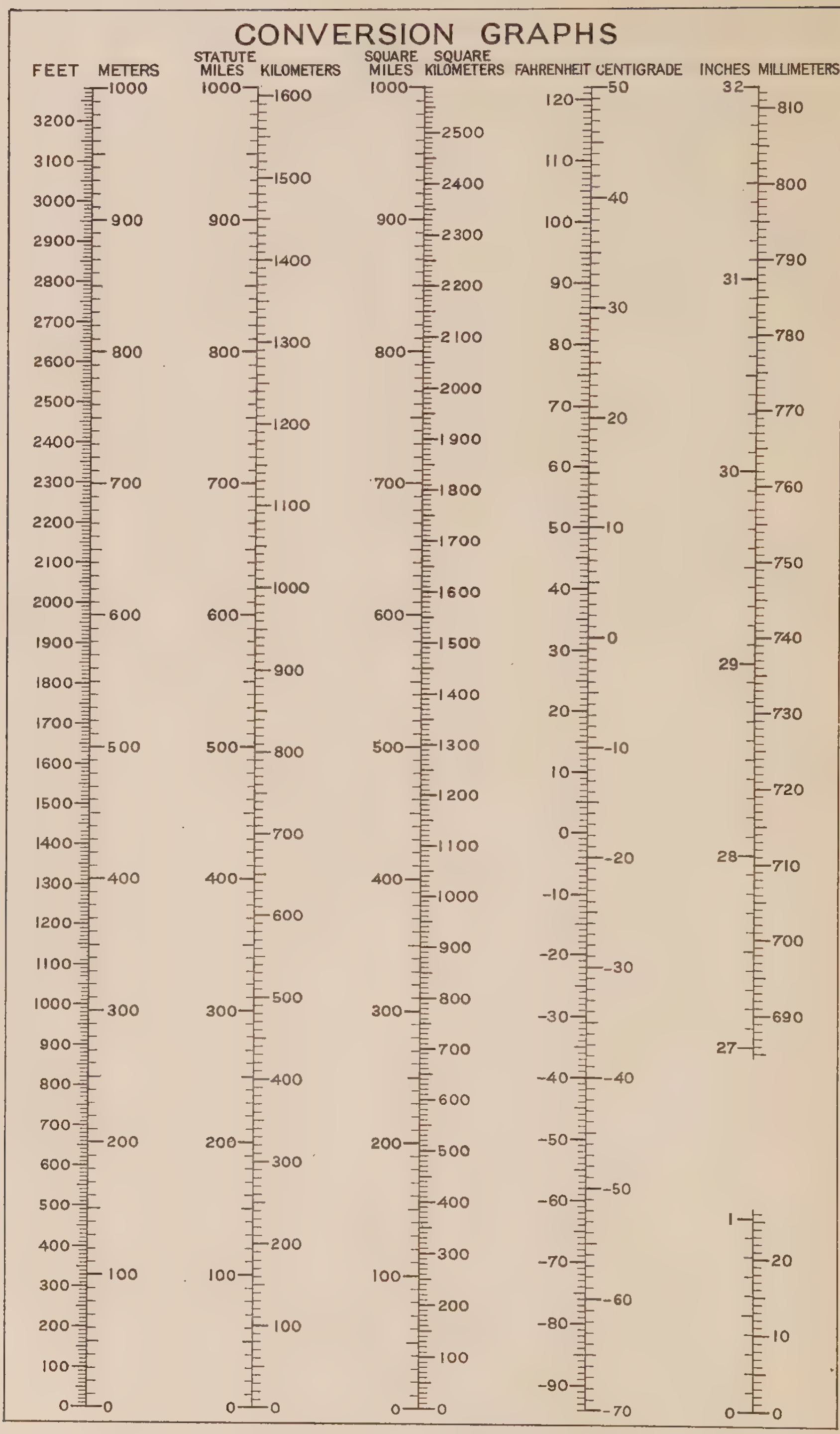
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